

FACTORS INFLUENCING THE EFFECTIVENESS
OF SODIUM CHLORATE AS A HERBICIDE¹A. S. CRAFTS²

INTRODUCTION

WITH THE RECOGNITION that the principal action of sodium chlorate on deep-rooted perennial weeds takes place through the soil^(1, 9, 10, 11) comes a clearer understanding of the importance of those factors that influence the absorption of this material from the soil. The newer concepts of chlorate action^(9, 10, 11) promise a distinct advance in the technical use of this chemical, especially in those regions where summer rains do not occur.

In regions of frequent summer rains, freezing winters, and relatively shallow soils, the chlorates have been notably effective as herbicides. In the western states, however, chlorates have given erratic results and in many instances have been practically worthless when applied in early summer as recommended in the more humid states.

Most of the deep-rooted perennials of the West blossom in April, May, or June, and chlorate sprays applied during these months lie in contact with organic matter, exposed to the decomposing action of the ultraviolet rays of the sun, from four to eight months before being leached into the soil. Though killing of the tops may be rapid and complete when the applications are made according to recommended methods, root killing is usually slight or absent; and by autumn, decomposition of the chlorate has greatly reduced its concentration. Winter rains are so variable in amount and distribution that the depth of leaching is uncertain. Root systems of the weeds may extend to depths of 10 to 20 feet or more and are seldom injured by freezing temperatures except in the extreme Northwest or at high elevations. The weeds, there-

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fore, have every advantage; and dosages of 2 to 6 pounds of sodium chlorate per square rod applied in the early summer often prove almost totally ineffective.

Though the field operator need not understand the principles involved in the toxic action of sodium chlorate, the experimenter must recognize fully the importance of the various factors influencing its effectiveness and must take the utmost advantage of all naturally occurring agencies to make the methods that he recommends as complete and efficient as possible.

In California in plot tests and in the field it is relatively easy to differentiate between the effects of chlorate applied through the soil and through the plant. As experiments have shown, roots may be killed by the action of chlorate applied through the plant; but this type of response, as a basis for weed-killing practice, is less reliable than treatment through the soil. Since both these effects are often encountered in the field and cannot easily be separated in regions of summer rainfall, the following results obtained in California may serve to establish their relative importance.

EXPERIMENTAL RESULTS

GREENHOUSE TESTS ON THE EFFECTS OF FOLIAGE AND SOIL APPLICATIONS OF CHLORATE

The first experiments are reported simply to confirm the results obtained by workers in New York^(1, 11) and Iowa.^(9, 10) They were designed to differentiate, under partially controlled conditions in the greenhouse, between the effects of chlorate applied to the tops of plants by spraying, and those of soil application.

The plants used were morning-glory (*Convolvulus arvensis* L.), growing in soil tubes 4 inches in diameter and 3 feet deep; and Russian knapweed (*Centaurea repens* L.) and hoary cress (*Lepidium draba* L.), growing in 12-inch earthenware pots. The soil was Yolo clay loam with a field capacity of approximately 30 per cent and a permanent wilting percentage of 14.

The treatments were: (1) Spraying of the foliage with 25 cc of 10 per cent NaClO_3 solution after having covered the soil carefully with dry sphagnum moss. The plants were in blossom and had had normal watering. Applications were made in the daytime. The moss and dead foliage were later removed so that no chlorate solution reached the soil. (2) Application to the soil of 250 cc of 1 per cent NaClO_3 solution, care being taken to avoid wetting the tops. A normal irrigation followed, and subsequent waterings were given when required by the untreated

TABLE 1

TESTS OF THE EFFECTS OF METHOD OF APPLICATION ON THE HERBICIDAL ACTION OF SODIUM CHLORATE, JANUARY 22, 1932

Tube or pot No.	NaClO ₃ concentration, per cent	Volume of solution, cc	Application to	Foliage	Condition of plants after				
					1 month	2 months	3 months	6 months	9 months
Morning-glory									
Russian knapweed									
1, 2, 3	10	25	Foliage	Present	Healthy resprouts	Normal growth	Normal	Normal	Normal
4, 5, 6	1	250	Soil	Present	Plants dead	Dead	Dead	Dead	Dead
7, 8, 9	1	250	Soil	Removed	Plants dead	Dead	Dead	Dead	Dead
10	Check	0	No application	Removed	Healthy resprouts	Normal growth	Normal	Normal	Normal
Hoary cress									
1, 2, 3	10	25	Foliage	Present	A few small resprouts	Healthy resprouts	Normal growth	Normal	Normal
4, 5, 6	1	250	Soil	Present	No resprouts	A few weak resprouts	Three weak resprouts	Plants dead	Dead
7, 8, 9	1	250	Soil	Removed	A few small resprouts	Weak chlorotic resprouts	Five weak resprouts	Four very weak resprouts	Plants dead
10	Check	0	No application	Removed	Healthy resprouts	Normal growth	Normal	Normal	Normal
Hoary cress									
1, 2, 3	10	25	Foliage	Present	A few healthy resprouts	Resprouts very healthy	Normal growth	Normal	Normal
4, 5, 6	1	250	Soil	Present	Leaves dead, shoot tips alive	Weak chlorotic growth at tips	Many weak chlorotic shoots	Plants recovering	Normal
7, 8, 9	1	250	Soil	Removed	A few chlorotic resprouts	A few chlorotic resprouts	Numerous chlorotic shoots	Plants recovering	Normal
10	Check	0	No application	Removed	Healthy resprouts	Normal growth	Normal	Normal	Normal

checks. (3) Applications similar to treatment 2 after removal of all top growth. Irrigations followed as in treatment 2. The results appear in table 1.

All tests were run in triplicate. There were untreated checks (not shown in the table) and checks with tops removed but with no application of chlorate.

Evidently spraying the foliage under the conditions of this experiment had an effect differing in no essential feature from simple removal by cutting. Though resprouting was slightly delayed and the shoots were somewhat chlorotic, they soon assumed a normal appearance and growth, with no sign of permanent injury to the roots.

Applying a like amount of chlorate to the soil resulted in the ultimate death of all morning-glory and Russian knapweed plants. Removing the tops hindered absorption, as did lowering the transpiration by other means in the Iowa experiments;⁽¹⁰⁾ Russian knapweed was killed somewhat more slowly than morning-glory under these conditions. Soil application caused severe injury to the hoary cress plants but did not kill them: as the chlorate disintegrated with rising greenhouse temperatures,⁽¹⁰⁾ the plants slowly recovered. A difference in susceptibility of different species was clearly shown.^(5, 6, 10)

This same experiment was conducted a second time with morning-glory plants with identical results. Evidently when plants in the blossoming stage, amply supplied with moisture, are sprayed with a chlorate solution during the day, there is practically no translocation of the chemical within the plant and no permanent injury.

PLOT TESTS: RELATION OF TIME OF APPLICATION AND RAINFALL TO EFFECTIVENESS OF CHLORATE

Since chlorate is effective when applied through the soil, it would seem logical in California to delay spraying until the winter rains begin. It would also follow that the ultimate location of the herbicide within a given soil would depend upon the amount and distribution of the rainfall and would be reflected by visible injury to roots growing in the soil.

Series of square-rod³ plots have been treated during the past three winter seasons in a study of the effects of rainfall on movement of chlorate in the soil. In each case, unless otherwise noted, treatment consisted of simply spraying the plot with a solution containing 3 pounds of sodium chlorate dissolved in 3 gallons of water. Before the frosts, applications were made to the living foliage and soil, the plots being left undisturbed. Later applications were made on the dead foliage and soil.

An even distribution of the chemical on the square-rod area was at-

³ All plots reported in this paper were one square rod in area.

tempted regardless of distribution of the weeds. The principal weed was morning-glory, and the treated plots were all heavily infested. The soil was Yolo loam. Table 2 gives the results of these experiments for the season 1931-32.

These plots show the influence of the various factors affecting chlorate sprays. The first three applications were subject to considerable decomposition as well as to leaching by the total seasonal rains. The

TABLE 2
THE RELATION OF RAINFALL TO RESPROUTING OF MORNING-GLORY TREATED WITH
SODIUM CHLORATE, 1931-32

Plot No.	Date of application	Condition of foliage	Rainfall, in inches		Estimated per cent resprouting,* 1932		
			Before	After	May 17	June 21	Nov. 21
1	Aug. 21, 1931.....	Alive.....	0	15.08	40	60	75
2	Sept. 15, 1931.....	Alive.....	0	15.08	45	70	75
3	Oct. 15, 1931.....	Alive.....	0	15.08	75	70	60
4	Nov. 15, 1931.....	Alive.....	1.49	13.59	80	85	40
5	Dec. 16, 1931.....	Dead.....	2.53	12.55	40	30	5
6	Jan. 20, 1932.....	Dead.....	10.47	4.61	1	2	25
7	Feb. 17, 1932.....	Dead.....	12.39	2.69	50	50	60

* The values given here and in succeeding tables for percentage of resprouting are visual estimates, not actual counts. One morning-glory plant may send up several hundred weak shoots from one injured root, while another may send up one or two relatively strong ones. In such cases a count means little. All estimates given in this paper were made by the writer, who considered not only the numbers of shoots but also their vigor. The values given, therefore, are more truly a measure of the effectiveness of the treatment than a count could possibly be.

chemical on the November plot was also subject to excessive leaching, but the toxic effects of the chlorate increased considerably during the season of 1932. The chemical was carried to a depth of about 5 feet in the December plot; and although it was dilute during the fore part of 1932, as the soil moisture decreased it reached a lethal concentration within the plants, so that very few survived the summer. In 1933 this plot and several others sprayed at the same time were devoid of morning-glory. The January plot received much less rainfall, and the roots were killed rather uniformly to a depth of 3 feet. They resprouted from this level, however, and made considerable growth by fall. Throughout 1933 they continued to improve; and in 1934 the plot was nearly normal. Roots in the February plots were killed only to a depth of 1 foot; and resprouting was vigorous, improving with time.

The results of plot tests of the following two seasons appear in tables 3 and 4. Since other than edaphic factors enter the problem where applications are made during late summer and fall, only the winter plots are included.

As rainfall was deficient during both these winters, only the early-sprayed plots showed satisfactory results. The erratic nature of rainfall

distribution is well illustrated in these tables. In all three of these winters, most of the rains occurred during a few heavy storms in December and January; and subsequent precipitation was insufficient to provide

TABLE 3
THE RELATION OF RAINFALL TO RESPROUTING OF MORNING-GLORY TREATED WITH
SODIUM CHLORATE, 1932-33

Plot No.	Date of application	Condition of foliage	Rainfall, in inches		Estimated per cent resprouting, 1933		
			Before	After	May 31	June 30	Nov. 17
1	Dec. 15, 1932.....	Alive.....	0.39	9.17	1	1	1
2	Dec. 20, 1932.....	Alive.....	1.51	8.05	7	7	5
3	Dec. 20, 1932.....	Alive.....	1.51	8.05	2	2	2
4	Dec. 30, 1932.....	Alive.....	2.56	7.00	15	15	10
5	Jan. 16, 1933.....	Dead.....	2.66	6.90	10	10	10
6	Jan. 30, 1933.....	Dead.....	6.33	3.23	40	75	75
7	Feb. 15, 1933.....	Dead.....	6.98	2.58	20	60	95
8	Mar. 1, 1933.....	Dead.....	6.99	2.57	90	95	90
9	Mar. 1, 1933.....	Dead.....	6.99	2.57	45	70	90
10	Mar. 15, 1933.....	Dead.....	7.69	1.87	35	80	90
11	April 1, 1933.....	Alive.....	8.94	0.62	95	95	95

TABLE 4
THE RELATION OF RAINFALL TO RESPROUTING OF MORNING-GLORY TREATED WITH
SODIUM CHLORATE, 1933-34

Plot No.	Date of application	Condition of foliage	Rainfall, in inches		Estimated per cent resprouting, 1934		
			Before	After	April 3	May 10	July 16
1	Dec. 10, 1933.....	Alive.....	1.77	9.36	15	10	15
2	Dec. 10, 1933.....	Hoed off.....	1.77	9.36	5	7	10
3	Dec. 10, 1933.....	Spaded under*..	1.77	9.36	1	2	5
4	Dec. 20, 1933.....	Alive.....	4.39	6.74	10	5	5
5	Jan. 1, 1934.....	Dead.....	5.59	5.54	15	75	90
6	Jan. 1, 1934.....	Spaded*.....	5.59	5.54	7	40	75
7	Jan. 10, 1934.....	Dead.....	6.61	4.52	20	75	100
8	Jan. 20, 1934.....	Dead.....	6.77	4.36	20	75	100
9	Feb. 1, 1934.....	Dead.....	6.78	4.35	7	40	100
10	Feb. 1, 1934.....	Spaded*.....	6.78	4.35	5	15	75
11	Feb. 10, 1934.....	Dead.....	7.44	3.69	35	75	100
12	Feb. 20, 1934.....	Dead.....	8.67	2.46	35	100	100
13	March 1, 1934.....	.....	9.99	1.14	50	100	100

* Plots 3, 6, and 10 received 2 pounds NaClO_3 , were spaded and then received 1 pound NaClO_3 .

proper penetration of the chlorate. The added effect of spading under a part of the chlorate is evident in plots 3, 6, and 10 of table 4; and in years of deficient rainfall this procedure might prove effective, a plow being used in field applications. As shown by the results on these plots, distribution of the chlorate in the soil is a factor of vital importance in the use of this chemical.

RELATION OF APPLIED WATER TO DEPTH OF PENETRATION OF CHLORATE

In the hope of finding a method by which to control more accurately the penetration of chlorate in the soil, several plots were prepared and treated in May, 1932. First they were hoed to remove the top growth, which was profuse and in the early stages of blossoming. Then, having been diked, four of the plots were irrigated, sprayed early the following

TABLE 5

THE EFFECTS OF SODIUM CHLORATE APPLICATION FOLLOWED BY IRRIGATION UPON HOED MORNING-GLORY PLOTS

Plot No.	First irrigation	NaClO ₃ spray	Second irrigation		Estimated per cent resprouting				
			Date	Am't, inches	Aug. 11, 1932	Nov. 21, 1932	May 31, 1933	June 30, 1933	Nov. 17, 1933
1	} May 24, 4 in.	May 25, a.m.	May 25 {	2	90	20	10	10	50
2				4	15	5	1	1	10
3				6	30	10	5	10	15
4				8	100	25	30	30	50
5	}	May 26, a.m.	May 26 {	2	50	25	10	15	40
6				4	40	10	7	7	20
7				6	60	5	2	5	15
8				8	50	5	2	2	4

* Irrigated after chlorate application only.

morning, and later in the day irrigated again with varying volumes of water, measured through a meter. The remaining four plots were sprayed without previous irrigation and then irrigated with measured volumes, corresponding to the second irrigation given the first four plots. The results appear in table 5.

Considering first the preirrigated plots, it appears that 2 inches of water after the chlorate application did not carry the chemical deep enough and that the plants resprouted from below. On the other hand, 8 inches of water resulted in too great a dilution, so that plants were able to survive and resprout. But 4 and 6 inches carried the chemical to the critical depth and gave the best results. In the dry plots the water bearing the chlorate penetrated to a lesser depth, since it moistened the soil to its field capacity as it descended. Here the 8-inch application gave the best results, and the control of the weed was excellent.

Though the results of this experiment are promising, work in the greenhouse on numerous soils has indicated that the fixing of chlorate depends largely upon soil type. Further studies along this line have been delayed to await the greenhouse experiments, which are in progress.

SODIUM CHLORATE AS A TRANSLOCATED SPRAY

Since, by using irrigation water, weeds could be treated through the soil with chlorate at almost any time of the year, it is desirable to determine the best season for the application. This should be known not only in relation to the seasonal effect upon chlorate decomposition in the soil, caused by differences in temperature, but also with respect to the various stages in the annual cycle of the plant. Spraying the living foliage of plants, on the other hand, always involves the complicating factor of rapid absorption and root killing by translocation of the toxic chemical within the plant. The mechanism responsible for this action has been fully described in connection with the use of acid arsenical sprays.^(7, 2, 4)

Where plants in full blossom, growing in a moist soil, are sprayed during the day with a chlorate solution, little or none of the chemical is translocated into the roots, as shown in table 1 and by many tests in the field⁽¹⁰⁾ and laboratory. When, on the other hand, all factors influencing rapid absorption and translocation are considered and the applications are made according to recommendations for the acid arsenicals, roots may be rapidly killed to depths of 3 feet or more. The results of plot tests presented in table 6 have been selected to indicate the relative effects of night spraying, concentration of the solution, differences in soil moisture, and the use of acid upon translocation and root killing.

When plot 4 is compared with plot 3, night spraying proves most effective. Plot 2 illustrates the effect of low concentration upon penetration of the spray solution. The inclusion of acid compensates not only for the low concentration but also for the difference between day and night spraying by shortening the time required for penetration of the solution. The temperature was high when these sprays were applied, and the acid solution began to discolor the leaves within 5 minutes after its application.

Finally, plot 8 shows the retarding effect of high soil moisture upon translocation. The results on plots 7 and 8 appear better than they really were, because of slower growth during the cooler period following the spraying. As the first rain in the fall of 1931 did not occur until October 22, the effects shown in the first six plots are produced entirely by differences in movement of the chlorate within the plants. The roots in plots 4, 5, 6, and 7 were dead to a depth of 2 feet or more within two weeks after spraying, and all resprouts were chlorotic, indicating sublethal amounts of chlorate at even greater depths.

RELATION OF STAGE OF GROWTH TO THE EFFECTS OF CHLORATE

Keeping in mind this rapid action of chlorate under certain conditions and the two points previously mentioned, namely the seasonal effect

upon chlorate decomposition and the relation of the growth cycle of the plant to effectiveness of sprays, a series of plots was treated to differentiate between application through the plant, through the soil, and a combination of both.

One group of three plots having mature plants and low soil moisture was treated on June 24, 1932. At the same time twelve other plots were hoed off clean and given a thorough irrigation. These were treated in

TABLE 6

THE EFFECT OF TIME OF DAY, ACIDITY, CONCENTRATION, AND SOIL MOISTURE UPON THE ROOT KILLING OF MORNING-GLORY BY SODIUM CHLORATE SPRAYS

Plot No	Spray solution		Time of application		Soil moisture	Resprouting	
	NaClO ₃ per sq. rod, in lbs.	H ₂ SO ₄ per sq. rod, in lbs.	Date, 1931	Hour		Date, 1931	Estimated per cent
1	1	.....	Aug. 20	4:00 p.m.	Low	Oct. 8	90
2	1	.....	Aug. 20	7:00 p.m.	Low	Oct. 8	90
3	3	.....	Aug. 20	5:00 p.m.	Low	Oct. 8	80
4	3	.....	Aug. 20	8:00 p.m.	Low	Oct. 8	10
5	1	1¼	Aug. 22	4:00 p.m.	Low	Oct. 8	10
6	1	1¼	Aug. 22	7:00 p.m.	Low	Oct. 8	10
7	3	.....	Sept. 28	3:45 p.m.	Low	Nov.23	5
8	3	.....	Sept. 28	3:15 p.m.	High	Nov.23	40

groups of three at later periods (table 7) as follows: one plot of each group was simply sprayed with 3 pounds of sodium chlorate in 3 gallons of water; one plot was hoed off clean and a like application made to the bare soil, followed by one 6-inch irrigation on the following morning; the third plot was sprayed in the evening, as was the first, and then irrigated on the following morning like the second. The first plot was allowed to stand for the remainder of the season with no further treatment; the second and third were hoed to form a mulch after the top soil became dry so that conditions were optimum for regrowth of the plants.

By November 21, 1932, there had been only one light rain totaling 0.08 inch; the treatment on the first of each group of three plots may therefore be considered at that time to have been effective only through the plant. Treatment on the second of each group was through the soil alone, and the third plot in each represents a combination of treatment through the plant and through the soil.

In the treatments through the plants, the relation of maturity and soil moisture to absorption and translocation in the plant is clearly shown. Results on the second plot in each group of three, show that midsummer is the poorest time to make soil applications. Two factors are involved in this response. According to tables 2, 3, 4, and 5, plants may be killed by

TABLE 7

EFFECTS OF SODIUM CHLORATE SPRAYS ON MORNING-GLORY; A COMPARISON OF TREATMENT THROUGH THE PLANT WITH TREATMENT THROUGH THE SOIL AND WITH COMBINATIONS OF PLANT AND SOIL TREATMENTS

Plot No.	Date, 1932	Stage of growth	Time, p.m.	Soil moisture	Treat-ment spray on	Time of irrigation, a.m.	Estimated per cent resprouting				
							Aug. 11, 1932	Nov. 21, 1932	May 31, 1933	June 30, 1933	Nov. 17, 1933
1	June 24	Mature with ripe seed.....	8:00	Low	Foliage	.....	30	10	10	15	10
2			4:15	Low	Soil	June 25, 9:00	60	60	20	25	50
3			7:15	Low	Foliage	June 25, 11:00	15	10	7	5	5
4	June 24	Full blossom with green seed.....	7:30	Medium	Foliage	.....	60	80	20	35	60
5			7:15	Medium	Soil	June 25, 8:30	75	70	30	60	70
6			7:00	Medium	Foliage	June 25, 8:05	40	40	20	30	60
7	July 18	Lush green with no blossoms.....	7:20	High	Foliage	.....	100	90	40	60	60
8			7:10	High	Soil	July 19, 8:30	75	60	20	40	60
9			7:00	High	Foliage	July 19, 8:00	20	10	7	7	10
10	July 31	Early blossom	7:30	High	Foliage	.....	0	30	25	25	30
11			7:20	High	Soil	Aug. 1, 8:30	0	35	20	20	25
12			7:00	High	Foliage	Aug. 1, 8:00	0	5	15	15	30
13	Aug. 31	Full blossom with green seed.....	7:00	Medium	Foliage	.....	...	25	15	15	25
14			7:20	Medium	Soil	Sept. 1, 8:00	...	40	15	20	25
15			7:30	Medium	Foliage	Sept. 1, 8:30	...	5	2	1	3
16	Sept. 15	Fully mature with ripe seed.....	7:00	Low	Foliage	.....	...	5	5	5	15
17			7:15	Low	Soil	Sept. 16, 8:00	...	40	10	10	20
18			7:30	Low	Foliage	Sept. 16, 8:30	...	2	1	1	5

chlorate present in the soil during the period of spring vegetative activity. By June the roots are well stored with starch again, and the plants do not respond so well to chlorate treatment. In view of the results on November 17, 1933 (table 7) and the success of winter (tables 2, 3, and 4) and spring (table 5) applications, the effect of high soil temperature at the time of application on decomposition of the chlorate becomes apparent.

The outstanding feature of this experiment is the increased effectiveness where a combination treatment is given. When advantage is taken of all factors influencing treatment through the plant and through the soil, the effects are apparently additive and the results optimum. This type of treatment should form the basis for a successful field practice provided all conditions can be properly met. The results in November, 1933, represent practical control on plots 3, 15, and 18.

EFFECTS OF PRETREATMENTS UPON THE RESULTS OF CHLORATE APPLIED THROUGH THE SOIL

Since chlorate absorbed by plants apparently lowers their starch reserves,⁽⁸⁾ possibly a weakening of the roots of morning-glory by continued reduction or removal of top growth would render the plants more susceptible to killing by this chemical. A number of plots were treated during the summer of 1932 with this in mind. One group of three was hoed at weekly intervals for twelve times; a second group was sprayed five times with 2 per cent sodium chlorate solution, a third with $\frac{1}{2}$ per cent sodium arsenite, and a fourth with Diesel oil. Included in this experiment was a fifth group of seven plots sprayed with the acid arsenical in July. One of these plots received no further treatment; three of them received varying amounts of sodium chlorate on January 15, 1933. The remaining plots in the fifth group and all plots in other groups received varying applications of sodium chlorate on December 16. The results appearing the following season are recorded in table 8.

When these figures are compared with those of table 3, the only pretreatment at all beneficial appears to have been the acid arsenical spray. All others apparently inhibited the absorption of the chlorate or altered its distribution in the soil. The plots that had received chlorate sprays showed the cumulative effects of this extra chlorate; but all these pretreatments, though designed to weaken the plants, seemed to make them more resistant as far as winter treatment with chlorate was concerned. The acid arsenical treatment killed them to a depth of 3 feet or more, and they failed to recover. As the additional injury from chlorate was enough to keep them from coming through, this combination treatment was of practical value. Since the same effect may be obtained in the fall

TABLE 8
EFFECTS OF PREVIOUS TREATMENT UPON RESULTS OF CHLORATE APPLICATIONS ON MORNING-GLORY

Plot No.	First treatment		Chlorate application		Estimated per cent resprouting, 1933		
	Date, 1932	Type	Date	Pounds applied	May 31	June 30	Nov. 17
1 } 2 } 3 }	June 24	Hoed 12 times at weekly intervals through season.....	Dec. 16, 1932	{ 1 2 3	25 10 15	40 15 15	50 40 20
4 } 5 } 6 }	July 1	Sprayed 5 times with 2 per cent NaClO ₃ through the season.....	Dec. 16, 1932	{ 1 2 3	30 30 10	30 30 10	15 15 10
7 } 8 } 9 }	July 1	Sprayed 5 times with 1 per cent As ₂ O ₃ through the season	Dec. 16, 1932	{ 1 2 3	50 30 10	60 30 10	70 40 10
10 } 11 } 12 }	July 1	Sprayed 5 times with Diesel oil through the season.....	Dec. 16, 1932	{ 1 2 3	40 20 20	65 20 20	85 20 40
13 } 14 } 15 }	July 11	Sprayed with the acid arsenical.....	Dec. 16, 1932	{ 1 2 3	3 2 1	4 2 1	30 15 1
16	July 11	Sprayed with the acid arsenical.....	.....	Check—no chlorate	15	25	50
17 } 18 } 19 }	July 11	Sprayed with the acid arsenical.....	Jan. 15, 1933	{ 1 2 3	2 2 1	4 2 1	30 20 5

from one treatment of chlorate alone, apparently a separate acid arsenical spray would be justified only under special conditions.

EFFECTS OF VARIOUS APPLICATION METHODS UPON RESULTS WITH AUTUMN SPRAYS

A number of plots were treated during the fall of 1932 to compare simple spraying with spraying followed by water sprays, irrigation, and sulfuric acid, all with and without subsequent irrigation. In the series were included straight soil treatments on hoed plots and a number of divided applications in which the chlorate dosage was put on in two and three separate applications. The results appear in table 9.

In interpreting the results of these tests, one should remember that the winter rains started in November. Any differences caused by the variations in treatment were therefore soon overshadowed by the results of absorption from the soil. The total season's rainfall, furthermore, was only 9.56 inches, so that the additional 6 inches applied to many of these plots probably did little more than compensate for the evaporation occurring during the six-month period of rainfall. All these plots fell, therefore, within the 8-to-12-inch requirement indicated in tables 2, 3, and 4, as necessary for proper distribution of the chemical.

In general better results were secured on the irrigated plots than on the unirrigated. Spraying with water or sulfuric acid on the morning after the chlorate application seemed to have no significant effect at this time of year. Irrigation immediately after spraying reduced the effectiveness considerably, as shown by plot 8. This same effect was noted in the early summer on similarly treated plots and on plots receiving the dry salt and immediate irrigation.

Dividing the application, aiming at a more uniform distribution of the chemical in the soil, had no significant effect. Apparently any treatment by which the tops of the plants are killed and the chlorate is subsequently leached to a proper depth in the soil gives excellent results at this time of the year.

An additional series of plots was treated during December, January, and February, making 1 and 2-pound applications at different intervals, each plot receiving a total of 3 pounds per square rod. There was no difference in these results, either, except where the bulk of the chemical was applied so late as to receive insufficient rain for proper leaching.

CUTTING AS A FINAL TREATMENT FOR CHLORATE-INJURED PLANTS

Two further experiments are of practical significance in the use of sodium chlorate. When the plants on the plots reported in table 5 were about 6 weeks old, they were very chlorotic and had practically stopped

TABLE 9
FALL TREATMENT; A COMPARISON OF VARIOUS METHODS OF APPLYING
SODIUM CHLORATE ON MORNING-GLORY

Plot No.	Treatment				Estimated per cent resprouting			
	No.	Date, 1932	Time	Type	Nov. 21 1932	May 31 1933	June 30 1933	Nov. 17 1933
1	1	Oct. 21	9:15 p.m.	Sprayed 3 lbs.....	0	1	1	5
2	1	Oct. 25	8:00 p.m.	Sprayed 3 lbs.....	0	3	5	10
3	1	Oct. 21	9:00 p.m.	Sprayed 3 lbs.....	0	1	1	5
	2	Oct. 22	8:00 a.m.	Sprayed water.....				
4	1	Oct. 25	8:30 p.m.	Sprayed 3 lbs.....	0	7	5	10
	2	Oct. 26	8:15 a.m.	Sprayed water.....				
5	1	Oct. 21	8:00 p.m.	Sprayed 3 lbs.....	0	2	2	5
	2	Oct. 22	8:15 a.m.	Sprayed water.....				
	3	Oct. 22	1:00 p.m.	Irrigated 6 in.....				
6	1	Oct. 21	8:45 p.m.	Sprayed 3 lbs.....	0	0	0	1
	2	Oct. 22	8:30 a.m.	Sprayed water.....				
	3	Oct. 22	2:00 p.m.	Irrigated 6 in.....				
7	1	Oct. 22	9:00 a.m.	Sprayed 3 lbs.....	0	0	1	3
	2	Oct. 25	1:00 p.m.	Irrigated 6 in.....				
8	1	Oct. 22	10:00 a.m.	Sprayed 3 lbs.....	0	60	50	20
	2	Oct. 22	10:15 a.m.	Irrigated 3 in.....				
	3	Oct. 24	1:00 p.m.	Irrigated 3 in.....				
9	1	Oct. 25	8:15 p.m.	Sprayed 3 lbs.....	0	2	3	7
	2	Oct. 25	9:15 p.m.	Sprayed H ₂ SO ₄				
	3	Oct. 26	8:00 a.m.	Sprayed water.....				
10	1	Oct. 21	8:50 p.m.	Sprayed 3 lbs.....	0	1	1	1
	2	Oct. 21	10:00 p.m.	Sprayed H ₂ SO ₄				
	3	Oct. 22	3:00 p.m.	Irrigated 6 in.....				
11	1	Oct. 24	2:00 p.m.	Irrigated 4 in.....	0	10	10	7
	2	Oct. 25	8:45 p.m.	Sprayed 3 lbs.....				
	3	Oct. 26	1:00 p.m.	Irrigated 6 in.....				
12	1	Oct. 24	10:00 a.m.	Foliage hoed off.....	0	2	1	2
	2	Oct. 24	10:30 a.m.	Sprayed 3 lbs.....				
	3	Oct. 25	1:30 p.m.	Irrigated 6 in.....				
13	1	Oct. 24	9:00 a.m.	Foliage hoed off.....	6	2	1	2
	2	Oct. 24	9:30 a.m.	Irrigated 4 in.....				
	3	Oct. 24	11:00 a.m.	Sprayed 3 lbs.....				
	4	Oct. 25	11:00 a.m.	Irrigated 6 in.....				
14	1	Oct. 21	8:15 p.m.	Sprayed 1 lb.....	0	15	10	5
	2	Oct. 22	9:30 a.m.	Sprayed water.....				
	3	Oct. 22	1:30 p.m.	Irrigated 2 in.....				
	4	Oct. 29	.....	Sprayed 1 lb.....			
	5	Oct. 29	.....	Irrigated 2 in.....			
	6	Nov. 5	.....	Sprayed 1 lb.....			
	7	Nov. 5	.....	Irrigated 2 in.....			

TABLE 9 (continued)

Plot No.	Treatment				Estimated per cent resprouting			
	No.	Date, 1932	Time	Type	Nov. 21 1932	May 31 1933	June 30 1933	Nov. 17 1933
15	1	Oct. 25	9:00 a.m.	Sprayed 1 lb.....	0	7	5	5
	2	Oct. 25	9:15 a.m.	Irrigated 2 in.....				
	3	Nov. 8	.....	Sprayed 1 lb.....			
	4	Nov. 8	.....	Irrigated 2 in.....			
	5	Nov. 22	.....	Sprayed 1 lb.....			
	6	Nov. 22	.....	Irrigated 2 in.....			
16	1	Oct. 21	8:30 p.m.	Sprayed 1 lb.....	0	3	3	4
	2	Oct. 22	9:15 a.m.	Sprayed water.....				
	3	Oct. 22	2:30 p.m.	Irrigated 2 in.....				
	4	Oct. 29	.....	Sprayed 2 lbs.....			
	5	Oct. 29	.....	Irrigated 4 in.....			
17	1	Oct. 21	8:40 p.m.	Sprayed 1 lb.....	0	1	1	4
	2	Oct. 22	8:45 a.m.	Sprayed water.....				
	3	Oct. 22	3:30 p.m.	Irrigated 2 in.....				
	4	Nov. 4	.....	Sprayed 2 lbs.....			
	5	Nov. 4	.....	Irrigated 4 in.....			
18	1	Oct. 25	8:00 a.m.	Foliage hoed off.....	0	5	5	5
	2	Oct. 25	8:30 a.m.	Sprayed 1 lb.....				
	3	Oct. 25	8:45 a.m.	Irrigated 2 in.....				
	4	Nov. 1	.....	Sprayed 1 lb.....			
	5	Nov. 1	.....	Irrigated 2 in.....			
	6	Nov. 8	.....	Sprayed 1 lb.....			
	7	Nov. 8	.....	Irrigated 2 in.....			
19	1	Oct. 24	8:00 a.m.	Foliage hoed off.....	0	7	5	3
	2	Oct. 24	8:30 a.m.	Sprayed 1 lb.....				
	3	Oct. 24	3:30 p.m.	Irrigated 2 in.....				
	4	Oct. 31	.....	Sprayed 2 lbs.....			
	5	Oct. 31	.....	Irrigated 4 in.....			
20	1	Oct. 24	2:30 p.m.	Foliage hoed off.....	0	15	5	5
	2	Oct. 24	3:00 p.m.	Sprayed 1 lb.....				
	3	Oct. 24	4:00 p.m.	Irrigated 2 in.....				
	4	Nov. 6	.....	Sprayed 2 lbs.....			
	5	Nov. 6	.....	Irrigated 4 in.....			

growing. As further injury might have weakened them even more, one-half of each plot was hoed about July 10 and again late in August. The results in table 5 are all for the unhoed portions. Table 10 gives the data for both hoed and unhoed plots.

The differences shown here are outstanding, especially on the plots where the degree of control was already high. According to common experience with sodium chlorate, a fairly satisfactory control may be obtained with a moderate application, but a much greater amount is required for complete eradication. Judging from these results, a few weed cuttings during the summer and fall after a spring application or during the summer after a winter application may go a long way toward

completing the work. The plants must be severely weakened, however, before this practice will give the desired results. Further tests on this method carried out in 1933 emphasize that only weak plants are affected by the treatment.

LEACHING TO RID THE LAND OF CHLORATE

The other point to be considered is the ridding of the land of residual chlorate after the weeds have been killed. Morning-glory in a field at Davis had been sprayed in the fall of 1930 with sodium chlorate. Figure

TABLE 10
RESULTS OF HOEING PLOTS SERIOUSLY AFFECTED BY CHLORATE

Plot No.	Treatment			Estimated per cent resprouting (1933)									
	Preirrigation, inches	NaClO ₃ , lbs.	Irrigation, inches	March 23		May 31		June 30		Aug. 12		Nov. 17	
				Un-hoed	Hoed	Un-hoed	Hoed	Un-hoed	Hoed	Un-hoed	Hoed	Un-hoed	Hoed
1	4	3	2	1	0	10	2	10	2	15	5	50	7
2			4	0	0	1	1	1	1	5	2	10	1
3			6	1	0	5	2	10	5	15	5	15	5
4			8	5	0	30	5	30	5	50	7	50	7
5	....	3	2	10	0	10	7	15	10	20	7	40	7
6			4	5	0	7	3	7	3	15	0	20	1
7			6	2	0	2	0	5	0	15	0	15	0
8			8	2	0	2	0	2	0	5	0	4	1

18 of the companion paper of this issue⁽³⁾ illustrates the sterile condition that existed. A total of about one acre was involved; and various treatments, including applications of ammonium sulfate, sulfur, and manure had been tried during the previous winter with no effect upon the sterility.

The tests that were run on the soil from these areas are described in the paper which follows.⁽³⁾ It suffices here to state that chlorate was present to a depth of 20 inches, with the highest concentration in the 4 to 8-inch level. Although 30 inches of rain had fallen since this chlorate was applied, little effective leaching had taken place. Rainfall, because of its intermittent nature, is less effective than water continuously applied as in irrigation. High soil temperatures, occurring only after considerable drying, also were ineffective in decomposing the chlorate.

After these tests the field was leached free of chlorate and later planted to alfalfa. The details of the process are given elsewhere.⁽³⁾ The leaching was entirely satisfactory and the alfalfa made normal growth through the first season. Leaching is apparently the most satisfactory method of ridding the land of chlorate where water is available.

DISCUSSION

Judging from experiments described in this paper, as well as field experience and a thorough review and interpretation of the literature, sodium chlorate may kill deep-rooted perennial plants by two separate and distinct types of action. These are (1) rapid absorption by the foliage and translocation to the roots through the vascular system of the plant and (2) absorption of the chemical from the soil by the roots. From a consideration of the mechanism involved and experience in the use of acid arsenical sprays, success by means of the first method alone seems limited by a very special set of requirements, often difficult to realize in the field.

The experimental results of Åslander,⁽¹⁾ Muenscher,⁽¹¹⁾ and the writer, together with the generally successful use of chlorates in the field by workers in regions of summer rains, show that the soil-application method is the more practical. Ideal conditions for this method, however, may not be readily found; and experiments reported in table 7 indicate that under certain conditions a combination of the two actions may give more favorable results than either alone. Evidently such a combined action often takes place where summer spraying is practiced in humid climates and largely accounts for the confusion in interpretation that occurs in the literature. Hulbert, Bristol, and Benjamin⁽⁶⁾ have emphasized the necessity of giving plot tests full time for action through the soil to reach completion, before passing judgment on the effectiveness of a given treatment. When the relative values of these two actions are fully appreciated, the many conflicting ideas that one finds in print concerning spray practice should be replaced by more rational recommendations.

According to Loomis and his colleagues,⁽¹⁰⁾ "... sodium chlorate dissolved in the soil water readily penetrates and kills the roots and rhizomes of either active or dormant plants." If this were true, with no reservations, all that would be necessary in killing deep-rooted weeds would be to expose the roots to chlorate in the soil moisture. The results of our winter applications might indicate that such treatment is successful.

But, although the roots may show some internal injury, movement of chlorate through the soil during the winter, as in plots 3 and 4, table 2, or in the spring, as in plot 4, table 5, was not sufficient to kill them. Loomis, *et al.*⁽¹⁰⁾ cite a similar instance in the spring of 1931 when an application of 600 pounds per acre of sodium chlorate, followed by 1½ inches of rain within 48 hours, failed to kill quack grass, although the subsoil contained toxic quantities of the chlorate. Evidently time enters

the problem, and the relative rates of chlorate movement and absorption are of vital importance. The rapid killing of many weeds after summer spraying and leaching by rains, compared with the slow killing of roots during the winter, as shown by many cases of heavy resprouting in the spring, followed by slow decline and death during the summer, indicates that dormant roots absorb chlorate from the soil at a slower rate than actively growing ones.

The many recommendations for early summer spraying that have come from eastern states, together with the results of the experiments cited in table 7, indicate that treatment later in the summer is also less effective. Though the temperature effect on chlorate decomposition is partly responsible for this, roots fully stored with starch are probably less susceptible to chlorate injury; for starch storage has been found to be a factor in the difference in susceptibility of various weed species. The evidence therefore seems to point to the spring season, from break of dormancy to the end of the vegetative period, as the optimum time for the effective absorption of chlorate from the soil.

The plot work presented in this paper indicates three possible methods for treating deep-rooted plants under California conditions.

1. Fall treatment, in which a certain amount of killing due to rapid absorption and translocation in the plant is followed by leaching and root absorption during the winter, spring, and summer. If this treatment is used in October, November, or early December, night spraying is unnecessary except in exceedingly dry spells. Optimum results however, will follow the close observance of all factors favoring absorption and movement through the plants. Fall rains of sufficient quantity to cause a flush of vegetative activity will practically nullify this effect through the plant.

2. Winter treatment, in which all absorption takes place from the soil. In this method the relation of soil type and rainfall to vertical distribution of the chlorate is of paramount importance. These points are receiving further study, but data presented indicate that the chemical must be present throughout the top 4-6 feet of soil in such a concentration as to become lethal at some time during the year. Too great dilution or a restricted distribution will limit the effectiveness of the treatment.

3. Spring application, followed by measured irrigation. This method simulates the condition encountered in regions of summer rains. Though it has not yet received extensive trial, it should give excellent results where carefully used. Here, again, soil type will largely determine the amount of water needed; and only where the relation of soil type to fixing of chlorate has been tested can the method be used with any assurance of success. Where flooding is used, the land must be level, to

insure uniformity in depth of moisture penetration. Sprinkling should give the best results if sufficient water is applied at a slow rate.

Differences in species susceptibility determine to a large extent the dosages to be recommended in using chlorates.^(5, 6, 11) Judging from experience in California, Russian knapweed, Canada thistle, and willows are among the easily controlled species; morning-glory, white horse nettle, Johnson grass, and Bermuda grass are more difficult; and hoary cress, camel's thorn, and nut grass require excessive amounts of chemical. These variations, as found in the field, depend upon differences in root permeability,^(12, 13) food reserves, root patterns, general growth habits, and ecologic factors determining species distributions, and are too complex for anything but empirical determination. Much of this work has already been done.⁽⁶⁾

Attempts at a more uniform distribution of chlorate in the soil by division of the dosage have not been effective, but in years of heavier rainfall or in soils with lower moisture-holding capacity such a procedure would probably insure against undue loss of chemical. Additional studies will be made on this phase of the problem as results of the soils work are obtained.

By hoeing off plants that had been severely injured by chlorate absorbed from the soil, the effectiveness of the treatment was increased. This practice is simple and inexpensive and should always be feasible.

Residual effects from chlorate applications are very common in regions of low summer rainfall. This, another problem involving the effect of soil type on chlorate behavior, will be treated further at a later date. If, however, irrigation water is not available for leaching, chlorates should be used with great discretion on lands where a rapid return to agricultural use is desired.

SUMMARY

Chlorates may kill deep-rooted perennial weeds (*a*) by rapid absorption and translocation within the plant and (*b*) by absorption from the soil by the roots. Experiments carried out in California serve to establish the relative importance of these two methods.

Daytime spraying of the foliage of greenhouse plants in blossom, with ample soil moisture, differed little from simple removal of tops by cutting.

Applying the same amount of chlorate to the soil killed morning-glory and Russian knapweed but only injured hoary cress.

Plot experiments carried on through three winters in California show that proper vertical distribution of chlorate within the soil by leaching of winter rains is essential to success with the soil-treatment method.

A similar vertical distribution may be accomplished by leaching with irrigation water.

Rapid absorption and translocation of chlorate through plants are conditioned by the same factors that control the action of acid arsenical spray.

Experiments designed to kill plants by chlorate action (*a*) through the plant, (*b*) through the soil, and (*c*) through both the plant and the soil, indicate that the third method is the most effective.

Pretreatments aimed at a weakening of plants decreased rather than increased the effects of chlorate. The acid arsenical treatment in July, however, followed by chlorate in December, was very effective. The July treatment killed the roots to a depth of 3 feet or more.

Fall sprays, applied in a number of ways, were all effective against morning-glory. The only type of fall treatment that failed was a spray followed immediately by irrigation that washed the chlorate into the soil, leaving the foliage intact. A number of experiments of this nature proved ineffective.

Division of the dose into two and three separate applications proved of no additional benefit in these experiments, either in the fall or winter treatments. In winters of high rainfall this method might avoid excessive loss.

Winter treatments were effective as long as the bulk of the chlorate was applied early enough to be leached well into the soil. Late applications failed.

Hoeing of plants severely injured by chlorate absorbed from the soil weakened them and proved a practical means of increasing the effects of a given treatment.

Continuous leaching with irrigation water proved the best means of ridding the land of residual chlorate. Sterile areas leached with 36 inches of water were returned to use within a season by this practice.

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THE TOXICITY OF SODIUM ARSENITE AND
SODIUM CHLORATE IN FOUR
CALIFORNIA SOILS

A. S. CRAFTS

THE TOXICITY OF SODIUM ARSENITE AND SODIUM CHLORATE IN FOUR CALIFORNIA SOILS¹

A. S. CRAFTS²

INTRODUCTION

SOIL STERILIZATION by means of chemicals has been practiced for many years. Among the agents used, arsenic is the most prominent. Recognized years ago^(8, 14) as particularly effective, it has been recommended by many workers^(8, 7, 13, 15) for controlling weeds in drives, walks, tennis courts, and various waste areas.

More recently the need for cheap and practical soil-sterilization methods has been indicated by consideration of (1) the dissemination by irrigation waters of the seeds from weeds growing on the ditchbanks, (2) the blocking of irrigation and drainage ditches by overhanging weed growth, (3) the harboring of insect pests and plant diseases by weeds in waste areas, and (4) the fire hazards of dry vegetation near roads, fire-breaks, buildings, and fences.

That the methods described in the literature have found such limited use is apparently explained by the lack of fundamental knowledge regarding the behavior of arsenic in soils. There is no basis for interpreting critically the results obtained in the field. When the responses of soils to arsenic treatment are clearly understood and when more satisfactory methods are devised for applying arsenic under field conditions, this chemical should be far more widely used as a soil sterilant.

A satisfactory agent for killing deep-rooted perennial weeds through the soil has long been sought. Åslander^(1, 2) showed that sodium chlorate may be successfully used for this purpose. Although his results were apparently overlooked in the hurried attempts to solve the country's weed problems by the use of this chemical as a foliage spray, recent works^(6, 9, 10, 11) point to soil treatment as the more logical method and indicate the need of a more consistent and reliable control practice than has been existent. Studies on the behavior of sodium chlorate in four western soils should assist materially the formulation of this practice.

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METHODS

The Soils.—Yolo clay loam, Stockton adobe clay, Fresno sandy loam, and Columbia fine sandy loam were selected for these studies. Samples were taken from the surface 2 inches, screened, sacked, and stored until used. The Columbia and Fresno soils were passed through a $\frac{1}{8}$ -inch mesh screen; the Yolo and Stockton through a $\frac{1}{4}$ -inch mesh.

The Yolo clay loam was obtained on the University Farm at Davis. According to Shaw's key,⁽¹²⁾ it is a secondary mineral soil with no sub-soil accumulations. Composed of material from sedimentary rocks, it is a brown soil of recent origin, with good drainage, very fertile, but heavy in texture and difficult to work when wet.

The Stockton adobe clay, a secondary mineral soil with a lime hardpan, is made up of materials from mixed or undetermined rock sources. It is semimature, black, and developed under restricted drainage. A typical adobe soil, it is high in clay, very sticky when wet, and characterized by extreme shrinkage upon drying. The sample was obtained near the Davis school northeast of Stockton.

The Fresno sandy loam, a secondary mineral soil derived from acid igneous rocks, is mature, with a well-cemented hardpan, brown to gray color, and only fair drainage. The sample was obtained near Hughson in Stanislaus County. It is a valuable agricultural soil, suited to deciduous fruits and many field crops, including alfalfa.

The sample of Columbia fine sandy loam was taken from a peach orchard on the west bank of the Sacramento River about 5 miles north of Broderick. A recent alluvial soil from mixed rock sources, with no definite horizons of removal or deposition, it is light grayish brown, well drained, fertile, and highly productive.

The moisture equivalents of these soils, as determined by Mr. C. H. Hofmann of the Irrigation Division are: Yolo clay loam 31.0, Stockton adobe clay 34.5, Fresno sandy loam 5.9, and Columbia fine sandy loam 19.8.

The Method.—After thorough consideration, the method adopted for studying toxic substances in soils was a biological test using Kanota oats as the indicator. This test gives a direct measure of the toxicity of the reagent without resort to chemical analysis and subsequent interpretation. It has proved simple and effective in determining the relative toxicity of various sterilants, and in studying the effects of time and cropping upon the permanence of their action.

In the toxicity tests a weighed amount³ of air-dry soil in a No. 2 can is moistened with a dilute solution of the chemical being tested. For rapid

³ For the Fresno sandy loam 600 grams; for the other three soils 500 grams.

and uniform distribution of the toxicant and water, one-third of the soil in the bottom of the can is moistened with one-third of the solution, a second portion of soil added and moistened, and then the last third added and the final volume of solution poured on. Thus the soil is uni-

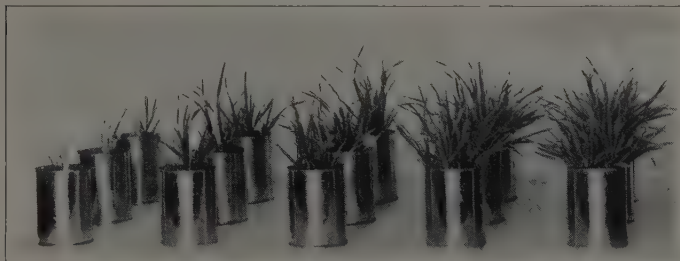


Fig. 1.—A toxicity series with sodium arsenite in Yolo clay loam. Concentrations, from left to right, 540 p.p.m., 405 p.p.m., 270 p.p.m., 135 p.p.m., 0 p.p.m., As_2O_3 in the air-dry soil. Three replicates.

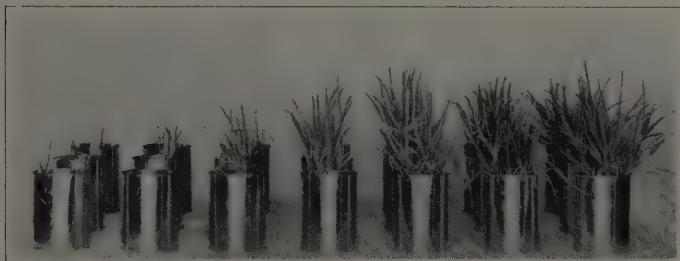


Fig. 2.—A toxicity series with sodium chlorate in Yolo clay loam. Concentrations from left to right, 540 p.p.m., 405 p.p.m., 270 p.p.m., 135 p.p.m., 75 p.p.m., 25 p.p.m., 0 p.p.m., NaClO_3 in the air-dry soil. Three replicates.

formly moistened in less than 1 minute. A comparison with cultures in which the finely ground chemical was mixed with air-dry soil and moistened indicated that the chemical also is effectively distributed. The volume of solution used is sufficient to bring the soil to field capacity.

After being moistened, all the cultures are allowed to stand overnight and are then seeded, 13 oats being placed in each can. They germinate in 4 to 5 days and are thinned to 10 plants at the end of about 12 days. The plants are watered by bringing them back to field capacity by weight as often as necessary. The data taken are the height and fresh weight of the plants 30 days from planting. Toward the end of this period a small excess of water is used to insure complete moistening of the soil mass.

TABLE 1

PRELIMINARY TESTS OF CHEMICAL STERILANTS IN YOLO CLAY LOAM

Chemical tested	Amount in air-dry soil	Yield of indicator plants									
		First run harvested Oct. 29, 1932		Second run harvested Jan. 22, 1933		Third run harvested May 6, 1933		Fourth run harvested Nov. 18, 1933		Fifth run harvested Jan. 14, 1934	
		Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
Sodium arsenate.....	<i>p.p.m.</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>
	15	29	10.3								
	30	32	10.7								
	60	32	10.7								
	120	30	9.6								
	180	31	9.5								
	240	30	8.7								
	300	30	8.0								
	375	29	7.4								
	450	29	6.8								
	600	28	6.0								
	Check	30	9.6								
Sodium arsenite.....	15	34	10.6	29	7.4	35	8.9	24	6.9		
	30	33	10.2	29	7.3	35	7.9	24	6.9		
	60	33	9.8	28	6.5	34	8.0	25	6.9		
	120	31	8.9	26	5.5	34	7.4	25	6.3		
	180	29	6.2	24	4.5	34	5.9	22	5.9		
	240	29	6.2	22	4.1	33	5.3	24	4.4		
	300	29	4.7	20	4.0	32	5.6	25	4.7		
	375	20	3.8	17	2.9	30	4.3	22	3.4		
	450	10	0.9	15	2.3	30	4.3	22	3.4		
	600	5	0.1	12	1.6	28	3.6	22	3.1		
	Check	31	10.5	28	7.4	35	8.7	26	7.1		
Sodium chlorate.....	15	33	11.3			36	8.9	24	6.6		
	30	33	10.8			35	8.8	26	7.1		
	60	31	10.2			35	8.4	27	7.7		
	120	30	8.4			34	7.9	27	7.6		
	180	28	5.9			33	7.7	27	7.1		
	240	25	4.9			33	6.8	27	7.1		
	300	23	3.8			32	5.9	26	6.5		
	375	20	2.8			31	5.5	25	5.5		
	450	13	2.5			29	4.3	24	5.0		
	600	15	1.4			28	3.0	24	4.3		
	Check	30	9.7			33	8.2	25	6.9		
Thallium sulfate.....	15	28	9.6			35	8.8			29	5.2
	30	28	8.6			35	8.7			30	5.8
	60	25	5.1			31	5.6			30	4.6
	120	20	1.8			23	2.9			22	3.2
	180	15	1.0			18	1.7			16	2.2
	240	10	0.5			10	0.6			12	1.5
	300	7	0.4			8	0.5			12	1.2
	375	4	0.2			7	0.4			11	0.9
	450	3	0.1			5	0.2			10	0.6
	600	3	0.1			3	0.2			8	0.5
	Check	28	9.4			33	8.3			30	5.3

In harvesting, the height of the plants is measured, a visual estimate being made of an average value. They are then cut off at the surface of the soil, broken into pieces about 3 inches in length, and weighed on an analytical balance. After weighing the plants are returned to the can from which they were taken.

Figure 1 presents a series selected to show the type of response ob-

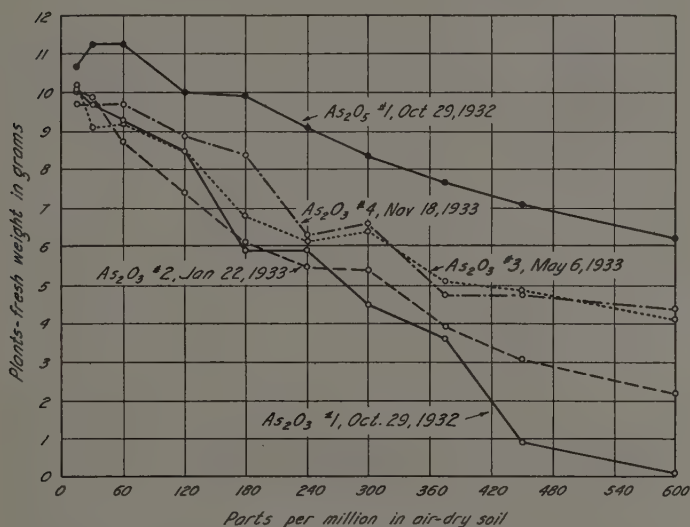


Fig. 3.—The relation of crop yield to the concentration of the arsenate and arsenite of sodium in Yolo clay loam.

tained with sodium arsenite; figure 2, a similar series with sodium chlorate.

After harvest, the cultures are air-dried for 30 days, and the soils are pulverized and remoistened, the previous crop being placed in the bottom of the can where it decomposes rapidly. They are seeded and handled as in the first run. This process is repeated as often as necessary for studying the behavior of the chemical with continued cropping.

Preliminary Toxicity Tests.—The first test to be described is a comparison in Yolo clay loam of the toxicities of several chemicals. The concentrations used are indicated in table 1, expressed as parts of chemical per million parts of air-dry soil. All of the test cultures were replicated three times; some of the checks were replicated six times. The values given are the arithmetic averages of the replicates.

For comparative purposes these data are expressed on the basis of

As_2O_3 for the sodium arsenate, As_2O_3 for the sodium arsenite, NaClO_3 for the sodium chlorate, and Tl_2SO_4 for the thallium sulfate. The data from table 1 are presented as graphs in figures 3 and 4. In all toxicity tests concentrations are given in parts per million of air-dry soil. Obviously the sodium arsenate is inferior as a soil sterilant. The trivalent arsenic is more toxic even after four croppings than the equivalent

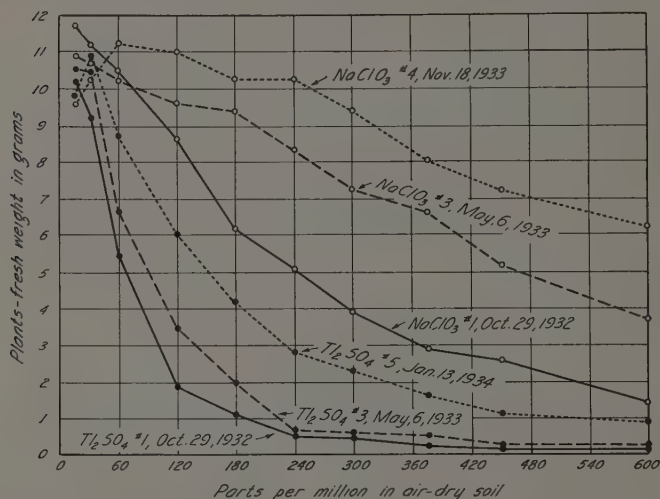


Fig. 4.—The relation of crop yield to the concentration of sodium chlorate and thallium sulfate in Yolo clay loam.

amount of the arsenate. Sodium chlorate compares very well with the arsenite but loses its toxicity more rapidly. Since the crop is returned to the can and nothing is lost from these cultures, this decrease in toxicity probably represents decomposition of the chlorate and fixation in a form unavailable to plants in the case of arsenite. Thallium sulfate is the most toxic of the chemicals tried: even with the fifth cropping, it is more effective than sodium arsenite. It also is gradually rendered unavailable to plants. Since sodium arsenite is the least expensive of these chemicals, it is the most practical for use in soil sterilization.

STUDIES WITH SODIUM ARSENITE

Judging by the variable results of numerous plot tests with sodium arsenite on California soils, definite knowledge concerning the toxicity and the fixing by the soil of this chemical must precede its use in soil-

sterilization practice. As the following experiments show, these properties vary widely in different soils; the results with the four distinct

TABLE 2
TOXICITY OF SODIUM ARSENITE IN FOUR CALIFORNIA SOILS,
AS SHOWN BY GROWTH OF INDICATOR PLANTS

Sodium arsenite expressed as p.p.m. As_2O_3 in air-dry soil	Yolo clay loam		Stockton adobe clay		Columbia fine sandy loam		Fresno sandy loam	
	Height	Weight	Height	Weight	Height	Weight	Height	Weight
First run harvested June 10, 1933								
<i>p.p.m.</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>
10	28	8.8	20	2.5	22	4.7	18	2.6
20	27	8.4	19	2.1	23	4.6	17	2.2
40	27	7.6	18	2.0	23	4.4	17	1.4
80	27	7.2	15	1.6	23	4.1	9	0.6
120	25	5.6	11	0.6	22	3.6	8	0.4
160	26	5.8	7	0.3	22	2.4	6	0.3
200	27	5.6	7	0.2	14	2.2	5	0.2
250	23	3.4	4	0.1	7	0.8	3	0.2
300	20	2.7	4	0.1	5	0.3	0	0.0
400	17	1.6	3	0.1	4	0.1	0	0.0
600	6	0.4	3	0.1	3	0.1	0	0.0
800	3	0.2	2	0.1	0	0.0	0	0.0
Check	27	8.4	21	3.0	23	4.4	19	3.0
Check	28	8.9	20	2.9	22	4.8	19	2.8

Third run harvested November 16, 1933

<i>p.p.m.</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>
10	31	7.8	23	3.1	30	7.1	27	4.8
20	32	8.1	22	3.0	30	6.8	27	4.7
40	32	8.5	23	2.9	30	7.1	27	4.6
80	32	7.9	23	2.9	30	6.6	27	3.9
120	32	7.7	22	2.8	29	5.9	24	2.8
160	33	7.0	22	2.3	29	5.5	22	1.9
200	32	6.7	20	2.2	28	4.6	21	1.8
250	31	6.4	19	2.0	26	3.5	18	1.5
300	30	5.4	17	1.9	25	3.1	17	1.5
400	29	4.3	14	1.5	22	2.2	14	0.9
600	27	3.6	10	0.6	21	1.9	9	0.3
800	24	2.8	8	0.3	16	1.3	7	0.2
Check	32	8.6	23	3.0	27	6.6	28	4.9
Check	33	8.6	22	2.8	29	7.1	27	4.7

soil types used do not enable one, at present, to predict the behavior of arsenic in untested soil.

Toxicity Tests.—The toxicity of sodium arsenite was studied in the four soils previously described. The results appear in table 2. Three crops were grown in these cultures; and the data for the first and third are given, the second being intermediate between them. All cultures were replicated five times, and the values presented are averages of the

five replicates. These data are illustrated in figures 5 and 6. For comparative purposes, the curves for the third run have been reduced to the base of the first run by multiplying all values by the factor

$$\frac{\text{Weight of first-run checks}}{\text{Weight of third-run checks}}$$

The soils used in these tests differ widely in crop-producing power

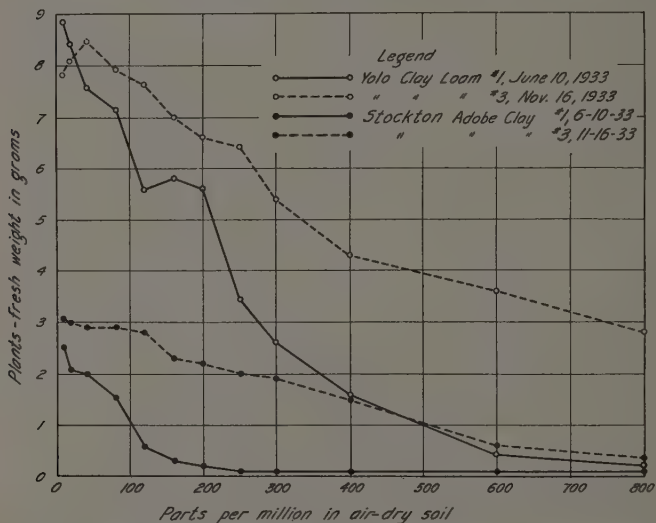


Fig. 5.—The relation of crop yield to the concentration of sodium arsenite expressed as As_2O_3 in Yolo clay loam and Stockton adobe clay.

under the conditions of the experiment. The two recent soils, Yolo clay loam and Columbia fine sandy loam, are very productive, the difference between them probably resulting mainly from the difference in texture. A Yolo fine sandy loam used in some other tests has given check plants very similar to those produced by the Columbia fine sandy loam of these experiments. On the other hand, the two more mature soils, though almost at the opposite extremes with regard to textural grade, produce very similar crops. The plants evidence a lack of nitrogen and fail to thrive after the first two weeks. The weather was cooler and growing conditions in the greenhouse were better in November than in June. This fact apparently favored growth of the plants in the two sandy soils but had little effect on those in the clays.

Concerning the toxicity of arsenic in these soils, two features are very prominent. In the first place, the differences in initial toxicity are large.

As shown by greenhouse tests on soils from sterile field plots, when the ten plants in a can weigh 1 gram or less, the soil may be considered sterile for all practical purposes, the weight of these small plants being made up chiefly of the stored material from the seed. If a weight of 1 gram or less is taken as the criterion of sterility, Stockton adobe clay (fig. 5) containing 100 p.p.m. of As_2O_3 is sterile, whereas 500 p.p.m. are re-

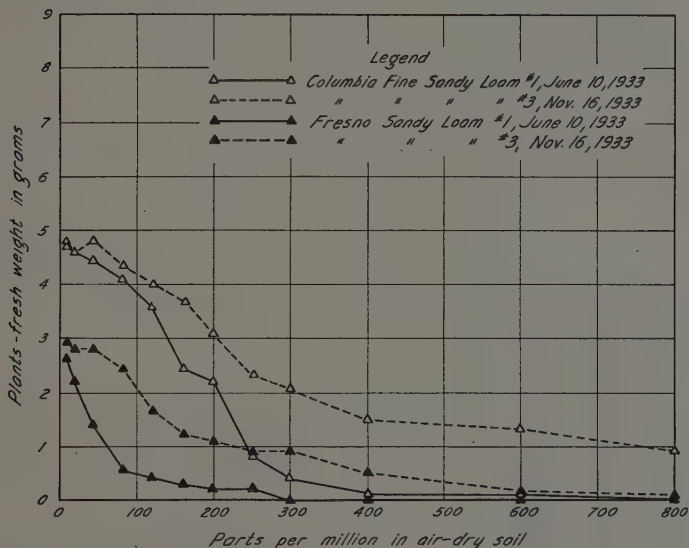


Fig. 6.—The relation of crop yield to the concentration of sodium arsenite expressed as As_2O_3 in Columbia fine sandy loam and Fresno sandy loam.

quired in Yolo clay loam. In Fresno sandy loam (fig. 6) 60 p.p.m. suffice, whereas in the Columbia fine sandy loam 240 p.p.m. are needed. These differences, related fundamentally to the chemical and physical nature of the soils, definitely limit the practicability of a soil-sterilization program where sodium arsenite is being used. Many anomalies of the field-plot tests may be satisfactorily explained by these findings, which, though they do not take the place of a comprehensive survey on the toxicity of arsenic in soils, point the way to such a survey and indicate its necessity.

The second interesting point about these curves is the large loss of toxicity where no arsenic is lost from the cultures. Much arsenic is evidently rendered unavailable to plants after its application to the soil. This fact probably explains the rapid decrease in effectiveness of light applications of arsenic in the field.

The Soil-Tube Tests.—Besides the initial toxicity, the ability of the soil to fix arsenic in a form available to plants is important in soil sterilization. This property of the soil determines the effective depth to which a given arsenic dosage will penetrate and its resistance to leaching rains.

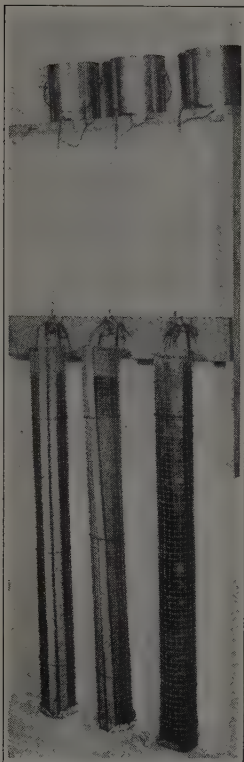


Fig. 7.—Apparatus for the soil-tube tests. Screw clamps are used to adjust the rate of flow. The center tube has been moistened only to a depth of about 5 inches. The other two are completely moist. Three of the ten units are shown.

A special type of soil tube greatly facilitates the study of the fixing power of soils for toxic chemicals. This tube consists of a celluloid sheet 10 inches wide and 36 inches long, bent to form a hollow cylinder and surrounded by a support of $\frac{1}{2}$ -inch mesh hardware cloth. In making up the tube, the lining and wire support are both lapped and the latter wired. A piece of filter paper held against the end by a square of $\frac{1}{8}$ -inch mesh hardware cloth closes the tube at the bottom. By laying the tube on a table and cutting the wires it can be opened and the soil removed in discrete fractions.

In the studies on the capacities of soils to hold arsenic, tubes filled with air-dry soil are slowly moistened from the top by dripping solutions on them until they are wet to the bottom. The apparatus used holds ten tubes, and solutions of the toxicant of varying concentrations are applied. In all soil-tube tests concentrations are given in parts per million in the applied solutions. A standard rate of moistening of 12 drops per minute from standard tips has been used. Figure 7 illustrates the moistening of the soil tubes. The soils are moistened in 24 to 48 hours, according to the volume of solution held.

When a complete set has been moistened, the tubes are allowed to stand for 24 hours and are then opened; the soil column is divided into weighed fractions. While moisture distribution is not uniform within this

time, experiments have shown that the lack of uniformity has no measurable effect upon the location of the chemical. Each fraction having been mixed and placed in a No. 2 can, the cultures are seeded and handled as in the previously described experiments.

The results of a complete series of these tests are given in table 3. Each culture represents a fraction of the soil column about 4 inches in height, and the 36-inch column yields nine such cultures. In the table the column headed "Depth" designates the location within the tube of the different

TABLE 3
THE FIXING POWER OF FOUR CALIFORNIA SOILS FOR SODIUM ARSENITE,
AS SHOWN BY GROWTH OF INDICATOR PLANTS

Soil type	Depth	H ₂ O check		As ₂ O ₃ 100 p.p.m.		As ₂ O ₃ 200 p.p.m.		As ₂ O ₃ 400 p.p.m.		As ₂ O ₃ 800 p.p.m.		As ₂ O ₃ 1200 p.p.m.	
		Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
Yoloclay loam; harvested June 15, 1933	<i>inches</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>
	0-4	20	4.2	8	0.6	5	0.1	4	0.1	2	0.0	1	0.0
	4-8	22	4.6	21	4.0	17	1.7	5	0.2	3	0.2	2	0.0
	8-12	22	5.3	22	4.8	22	4.8	21	3.5	6	0.2	5	0.1
	12-16	23	5.8	22	5.5	23	5.3	23	4.8	23	5.4	23	4.1
	16-20	24	6.4	23	6.0	25	6.5	23	4.8	24	6.1	24	5.6
	20-24	24	6.4	24	7.1	26	8.0	25	5.5	26	6.5	24	6.3
	24-28	24	8.1	26	8.5	27	8.6	25	6.8	25	7.4	25	6.8
	28-32	25	7.1	27	7.7	26	7.6	29	8.8	28	7.5	25	6.9
	32-36	24	6.4	24	5.6	24	5.5	26	4.1	23	5.3	24	5.3
	Check*	24	6.4	24	6.6	25	6.8	25	7.2	24	6.0	24	6.5
Stockton adobe clay; harvested July 12, 1933	0-4	17	2.9	6	0.1	3	0.1	3	0.1	0	0.1	0	0.0
	4-8	16	2.6	13	1.6	8	0.4	6	0.1	1	0.1	0	0.0
	8-12	15	2.8	15	2.5	16	2.3	14	1.6	5	0.1	3	0.1
	12-16	16	2.6	15	2.6	16	2.3	15	1.8	9	0.8	5	0.1
	16-20	15	2.6	17	2.7	16	2.6	16	2.0	18	3.2	15	2.5
	20-24	15	2.6	16	2.5	17	2.8	16	2.6	17	2.6	17	2.7
	24-28	15	2.5	14	2.6	16	2.5	17	3.0	16	3.0	16	2.9
	28-32	15	2.8	16	2.9	17	2.7	17	3.1	16	2.6	17	3.1
	32-36	14	2.5	14	2.6	17	2.9	17	2.9	17	3.0	17	3.2
	Check*	18	2.6	18	2.4	18	2.8	18	2.9	19	2.9	19	2.7
Columbia fine sandy loam; harvested July 23, 1933	0-4	22	3.5	7	0.5	5	0.2	5	0.1	0	0.0	0	0.0
	4-8	24	3.8	20	2.4	10	0.8	6	0.4	0	0.0	0	0.0
	8-12	26	4.0	24	3.9	25	4.1	14	1.8	0	0.0	0	0.0
	12-16	24	3.4	25	4.0	24	3.6	22	3.4	28	4.0	16	1.4
	16-20	26	4.0	26	4.4	26	3.9	26	3.9	27	4.1	27	4.3
	20-24	25	4.0	26	4.2	26	4.1	28	4.7	26	4.1	28	4.3
	24-28	24	3.9	27	4.3	28	4.4	28	4.5	28	4.8	29	4.7
	28-32	25	4.4	27	4.1	28	4.8	29	4.9	28	4.6	28	4.2
	32-36	30	6.3	28	5.0	29	5.5	30	5.8	32	6.8	30	4.8
	Check*	27	4.0	29	4.7	29	4.6	30	4.8	28	4.4	27	4.0
Fresno sandy loam; harvested June 29, 1933	0-4	18	3.1	10	0.5	7	0.2	4	0.1	4	0.1	0	0.0
	4-8	21	3.4	14	0.8	9	0.3	6	0.2	5	0.1	4	0.1
	8-12	18	3.3	18	2.5	16	1.3	10	0.5	5	0.2	4	0.1
	12-16	21	3.7	19	3.0	20	3.4	18	2.5	7	0.3	6	0.1
	16-20	21	3.3	19	3.2	19	3.2	18	3.2	19	2.6	17	1.3
	20-24	21	3.9	20	3.8	19	3.5	19	3.4	18	3.1	19	3.4
	24-28	21	3.7	19	3.5	18	3.6	19	3.6	18	3.1	18	2.8
	28-32	18	3.3	18	3.0	19	3.1	18	2.8	17	3.3	16	2.5
	32-36	16	3.4	17	3.7	15	3.0	17	3.3	16	3.1	16	2.7
	Check*	19	3.4	20	3.7	20	3.6	19	3.6	20	3.6	21	3.7

* These checks were cultures in air-dry soil moistened and planted, with no other treatment.

fractions. When the crop is very small, the arsenic is present in a lethal concentration; in the remainder of the column the arsenic is absent, or present only in sublethal amounts. In the Yolo and Columbia soils the crop in the lower fractions is above that of the checks because of leaching of readily soluble nutrients. Such materials were apparently absent from the Stockton and Fresno soils. The checks given at the bottom of

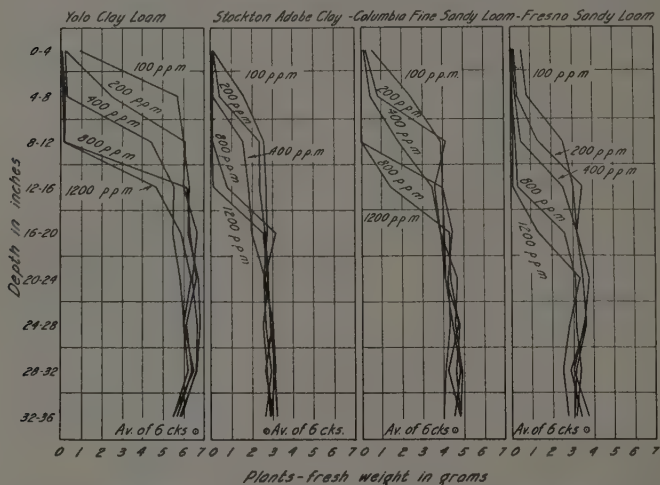


Fig. 8.—The relation of crop yield to penetration of sodium arsenite into columns of four California soils, showing their fixing power for this chemical.

each soil are simply cultures made up of the air-dry soils moistened with water and planted.

The results are shown in figure 8. By means of check tubes moistened with water alone, and notes on the depth of penetration of the solutions, the graphs of the results in the Yolo and Columbia soils have been corrected for the leaching of nutrients, since this effect only lends confusion to the curves and has nothing to do with the toxicity of the sterilant. The results on the four soils do not appear to differ very much; but when the amount of water required to moisten the columns is considered, the capacities of the soils will be found to vary considerably.

Considering that practically all the arsenic applied to these tubes is held in the fractions showing reduced growth, and that the amount originally present in the water occupying the fractions showing normal growth is a measure of the amount fixed, values have been computed (table 4) for the fixing power of these soils for arsenious ions when ap-

plied as dilute solutions of sodium arsenite. Obviously, these soils differ widely in fixing power for arsenic in the form applied. The capacity of the Yolo soil was approximately twice that of the Stockton and Columbia soils and about four times that of the Fresno sandy loam. With increasing concentrations of the solution applied, furthermore, the amount of chemical held was greater, more than twice as much being fixed from the solution of 1,200 p.p.m. as from that containing 100 p.p.m. Judging by these results, the depth of penetration of a given dosage de-

TABLE 4

THE FIXING POWER OF FOUR CALIFORNIA SOILS FOR ARSENIOS ARSENIC, EXPRESSED IN PARTS OF As_2O_3 PER MILLION PARTS OF AIR-DRY SOIL

Soil type	Air-dry soil per tube, in kilos	Solution per tube, in cc	Concentration of As_2O_3 in applied solution, in parts per million of solution				
			100	200	400	800	1,200
			As_2O_3 fixed by the soil, in parts per million of air-dry soil				
Yolo clay loam.....	5.0	1,500	270	278	372	480	622
Stockton adobe clay....	6.0	1,400	138	180	272	280	350
Columbia sandy loam.....	5.5	1,150	114	167	218	335	380
Fresno sandy loam.....	6.5	850	56	64	105	131	150

pends not alone upon the amount applied but also upon the type of soil and upon the concentration in which the arsenic moves through the upper soil layers.

The effects of leaching upon the concentration and distribution of arsenic in soil columns has been studied by slightly modifying the technic just described. Tubes of the soils were slowly moistened with a sodium arsenite solution containing 400 p.p.m. of As_2O_3 . After the initial moistening, distilled water was applied at the same rate as the solution, varying amounts of water being added to the different tubes in a series. When flow from the tubes had ceased, they were removed from the rack shown in figure 7 and allowed to stand in air-dry soil until all excess moisture had drained away. They were then opened. The soil was divided, placed in nine cans, and planted as before. The data from these experiments appear in tables 5, 6, 7, and 8 and figures 9 and 10.

Here again there are fundamental differences in the response of the four soils to this leaching treatment. In the Yolo clay loam 5 surface centimeters of water moved the chemical into the third fraction in lethal concentration, and 10 surface centimeters moved it into the fourth fraction. With 20 and 40 surface centimeters there was little further change. As the amount of leaching was again doubled, the available arsenic was

washed from the fourth fraction and reduced in the third; and with 160 surface centimeters it was further reduced in the third and somewhat lowered in the second. Through all this leaching, arsenic remained in the top fraction in lethal concentration.

TABLE 5
RESULTS OF LEACHING SODIUM ARSENITE IN YOLO CLAY LOAM, AS
SHOWN BY GROWTH OF INDICATOR PLANTS
(Harvested June 25, 1933)

Depth	0 cm H ₂ O		5 cm H ₂ O		10 cm H ₂ O		20 cm H ₂ O		40 cm H ₂ O		80 cm H ₂ O		160 cm H ₂ O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
As ₂ O ₃ —400 p.p.m. in moistening solution														
inches	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm
0-4	4	0.1	5	0.2	4	0.1	5	0.1	8	0.2	7	0.2	6	0.2
4-8	5	0.2	11	0.6	11	0.7	11	1.1	9	0.4	7	0.3	18	1.1
8-12	21	3.5	9	0.6	11	1.1	13	1.0	12	0.6	14	1.4	16	2.2
12-16	23	4.8	19	3.2	14	1.0	13	0.7	11	0.8	22	4.8	22	4.3
16-20	23	4.8	23	4.8	19	3.2	22	5.0	22	4.1	24	5.3	23	5.5
20-24	25	5.5	21	4.9	21	5.6	23	5.2	24	5.2	24	5.9	23	4.9
24-28	25	6.8	20	4.7	19	4.3	22	4.8	23	4.8	25	5.6	23	5.2
28-32	29	8.8	21	4.6	21	4.8	21	4.6	23	4.8	24	5.4	24	5.1
32-36	26	4.1	22	6.0	20	5.0	20	4.6	21	4.7	25	5.8	23	5.4

Check tubes—moistened with water

inches	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm
0-4	19	4.7	19	4.3	.....	.....	22	4.8	.....	.....	21	4.7
4-8	21	5.5	20	4.5	.....	.....	22	5.5	.....	.....	21	5.5
8-12	22	5.6	20	5.2	.....	.....	21	5.3	.....	.....	21	5.1
12-16	22	5.4	20	5.0	.....	.....	22	6.0	.....	.....	22	5.0
16-20	22	5.5	21	5.0	.....	.....	21	4.8	.....	.....	22	5.3
20-24	23	5.6	21	5.5	.....	.....	22	5.4	.....	.....	22	5.0
24-28	23	6.2	21	5.6	.....	.....	22	5.4	.....	.....	21	4.6
28-32	22	5.7	23	6.4	.....	.....	21	5.0	.....	.....	20	4.9
32-36	24	7.2	23	7.1	.....	.....	20	4.6	.....	.....	20	4.4
Check*	25	7.2	26	8.2	25	7.8	24	6.7	25	8.0	25	6.9	.....	.....

* These checks were cultures in air-dry soil moistened and planted, with no other treatment. Average weight of the 6=7.5 grams.

In the Stockton adobe clay the arsenic was considerably more mobile. Each increase in the volume of water applied moved the arsenic downward, until with 160 surface centimeters it was present in the lowest fraction in lethal concentration. With this highest volume, however, it had begun to decrease in concentration in the upper fraction; and further leaching would undoubtedly have washed more and more of it from the top of the column.

In the Columbia fine sandy loam the movement was greater than in the Yolo soil, but somewhat less than in the Stockton soil. Growth was not completely inhibited in the lowest fraction even after leaching with

160 surface centimeters of water, but it had increased a bit in the upper fractions.

The toxicant moved most readily in the Fresno sandy loam. Although considerably less arsenic was applied to this soil than to the others, be-

TABLE 6
RESULTS OF LEACHING SODIUM ARSENITE IN STOCKTON ADOBE CLAY,
AS SHOWN BY GROWTH OF INDICATOR PLANTS
(Harvested July 23, 1933)

Depth	0 cm H ₂ O		5 cm H ₂ O		10 cm H ₂ O		20 cm H ₂ O		40 cm H ₂ O		80 cm H ₂ O		160 cm H ₂ O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
As ₂ O ₃ -400 p.p.m. in moistening solution														
<i>inches</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>
0-4	3	0.1	0	0.0	4	0.1	4	0.1	5	0.1	7	0.2	10	0.8
4-8	6	0.1	3	0.1	4	0.1	3	0.1	5	0.1	6	0.1	8	0.2
8-12	14	1.6	7	0.1	5	0.1	4	0.1	5	0.1	5	0.1	6	0.1
12-16	15	1.8	14	2.2	8	0.3	6	0.1	5	0.1	7	0.1	8	0.2
16-20	16	2.0	13	1.9	13	1.7	9	0.6	7	0.1	6	0.1	7	0.1
20-24	16	2.6	14	1.8	14	1.9	13	1.7	12	1.1	7	0.1	9	0.1
24-28	17	3.0	15	1.9	14	2.0	15	2.3	14	2.1	14	1.3	8	0.3
28-32	17	3.1	13	1.9	13	1.8	14	1.7	14	2.0	12	1.3	7	0.1
32-36	17	2.9	10	1.3	12	1.3	13	1.5	13	1.7	10	0.9	7	0.2

Check tubes—moistened with water

<i>inches</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>
0-4	12	1.3	13	1.6	....	....	13	1.9	....	....	15	2.2
4-8	12	1.6	13	1.8	....	....	14	2.0	....	....	14	2.1
8-12	13	1.7	12	1.9	....	....	14	2.1	....	....	15	2.0
12-16	13	1.8	13	1.8	....	....	14	2.0	....	....	14	1.9
16-20	13	1.9	14	2.2	....	....	14	1.9	....	....	15	2.2
20-24	12	1.6	13	1.9	....	....	15	2.3	....	....	14	2.2
24-28	12	1.7	14	2.0	....	....	14	1.9	....	....	15	2.1
28-32	14	2.0	13	2.0	....	....	12	1.9	....	....	15	2.1
32-36	13	1.6	12	1.8	....	....	12	1.4	....	....	15	2.2
Check*	18	2.9	16	2.4	17	2.5	16	2.1	17	2.5	18	2.7	....	....

* These checks were cultures in air-dry soil moistened and planted, with no other treatment. Average weight of the 6=2.5 grams.

cause of the small volume of solution required to moisten the soil column, and although the total toxic effect was somewhat less pronounced, the chemical had started to move out of the top fraction after leaching with 20 surface centimeters of water; and with 160 surface centimeters it was mostly lost from the soil. This is a distinctly different behavior from that of the other three soils.

Discussion of Sodium Arsenite Studies.—The data presented in this paper, though quantitative for the experiments described, will require careful interpretation before they can be used in practical work. In the field, sterilized soils are subject to numerous and complex influences

that tend to alter the effects of a given treatment in a variety of ways. The plants that attempt to grow in these soils find conditions altogether different from those of the greenhouse. The common method of applying

TABLE 7
RESULTS OF LEACHING SODIUM ARSENITE IN COLUMBIA FINE SANDY LOAM,
AS SHOWN BY GROWTH OF INDICATOR PLANTS
(Harvested February 3, 1934)

Depth	0 cm H ₂ O		5 cm H ₂ O		10 cm H ₂ O		20 cm H ₂ O		40 cm H ₂ O		80 cm H ₂ O		160 cm H ₂ O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
As ₂ O ₃ —400 p.p.m. in moistening solution														
inches	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm
0-4	5	0.1	6	0.3	6	0.3	8	0.6	11	0.8	12	1.2	14	1.3
4-8	6	0.4	7	0.4	7	0.4	7	0.5	8	0.5	11	0.9	14	1.6
8-12	14	1.8	14	1.1	10	0.7	8	0.5	8	0.5	12	0.9	15	1.3
12-16	22	3.4	21	3.8	23	3.5	11	0.8	8	0.5	11	0.7	14	1.4
16-20	26	3.9	23	4.2	25	3.3	23	3.4	10	0.6	10	0.6	10	0.7
20-24	28	4.7	26	4.6	24	4.0	25	4.1	23	3.0	10	0.6	11	0.9
24-28	28	4.5	25	3.9	25	3.8	25	4.0	25	4.0	10	0.6	11	0.7
28-32	29	4.9	25	4.8	25	3.8	26	4.1	25	3.9	13	1.1	11	0.7
32-36	30	5.8	24	4.5	25	4.5	26	4.2	24	3.5	18	2.3	12	1.0

Check tubes—moistened with water

inches	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm
0-4	21	3.2	24	3.2	.....	.....	21	3.4	.....	.....	22	2.6
4-8	24	4.5	25	4.3	.....	.....	24	3.8	.....	.....	21	2.6
8-12	23	3.7	24	3.9	.....	.....	24	3.4	.....	.....	22	3.0
12-16	25	4.5	20	3.2	.....	.....	23	3.1	.....	.....	23	3.3
16-20	24	4.3	23	3.0	.....	.....	22	3.1	.....	.....	22	3.1
20-24	24	4.6	23	3.1	.....	.....	24	3.3	.....	.....	22	3.3
24-28	25	4.2	25	3.6	.....	.....	24	3.8	.....	.....	21	3.1
28-32	26	4.5	26	4.1	.....	.....	23	3.3	.....	.....	21	2.7
32-36	24	4.0	24	4.0	.....	.....	22	3.1	.....	.....	20	2.8
Check*	30	4.8	26	4.3	28	4.6	24	4.2	27	4.0	26	4.3	.....	.....

* These checks were cultures in air-dry soil moistened and planted, with no other treatment. Average weight of the 6=4.4 grams.

arsenic to the soil, furthermore, differs from that used in the experiments.

On the other hand, certain responses observed in this work are fundamental and will occur, though with a possible variation in degree, wherever arsenious arsenic comes in contact with soils.

As compared with other common sterilants, sodium arsenite is superior from several angles. It is as toxic as sodium chlorate in equivalent dosages, and is less subject to losses from decomposition and leaching. Though less toxic than thallium sulfate, it is by far the most economical chemical, on a cost basis, to use for soil sterilization.

In practical soil sterilization the differences in toxicity of arsenic in

different soil types are of fundamental importance. As plot tests have demonstrated, 2 pounds of As_2O_3 per square rod are as effective on Fresno sandy loam as 8 pounds on Yolo clay loam. Though these two types probably represent the extremes of a large number of agricul-

TABLE 8
RESULTS OF LEACHING SODIUM ARSENITE IN FRESNO SANDY LOAM,
AS SHOWN BY GROWTH OF INDICATOR PLANTS
(Harvested July 8, 1933)

Depth	0 cm H_2O		5 cm H_2O		10 cm H_2O		20 cm H_2O		40 cm H_2O		80 cm H_2O		160 cm H_2O	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
As ₂ O ₃ —400 p.p.m. in moistening solution														
inches	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm
0-4	4	0.1	0	0.0	6	0.2	15	1.1	17	1.6	22	2.6	19	2.3
4-8	8	0.2	0	0.0	5	0.1	11	0.8	16	1.7	20	2.3	18	1.7
8-12	10	0.5	0	0.0	5	0.2	9	0.5	15	1.6	19	1.8	19	2.0
12-16	18	2.5	7	0.4	5	0.2	8	0.4	15	1.4	18	1.9	19	1.8
16-20	18	3.2	12	2.0	7	0.3	10	0.5	18	1.9	19	1.7	21	2.4
20-24	19	3.4	16	2.6	13	1.6	9	0.6	12	0.9	16	1.5	21	2.3
24-28	19	3.6	16	3.0	17	3.3	19	2.5	16	1.4	18	1.9	21	2.4
28-32	18	2.8	14	2.8	17	3.2	17	2.4	18	1.7	17	1.7	21	2.6
32-36	17	3.3	17	3.1	18	3.7	16	2.4	18	2.4	16	1.5	20	2.2

Check tubes—moistened with water

inches	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm
0-4	19	2.9	20	3.1	....	.....	20	3.5	....	.....	20	3.1
4-8	21	3.0	22	3.5	....	.....	20	3.1	....	.....	19	3.0
8-12	21	3.0	23	3.5	....	.....	21	3.6	....	.....	21	3.6
12-16	19	3.2	22	3.6	....	.....	21	3.5	....	.....	21	3.7
16-20	21	3.3	22	3.9	....	.....	22	3.9	....	.....	21	3.6
20-24	21	3.5	21	3.9	....	.....	22	3.9	....	.....	21	3.5
24-28	20	3.2	23	3.8	....	.....	20	3.8	....	.....	21	3.4
28-32	20	3.4	21	3.1	....	.....	18	3.6	....	.....	21	3.4
32-36	18	3.1	22	3.2	....	.....	19	3.0	....	.....	20	3.0
Check*	19	3.6	22	3.5	22	4.0	22	3.7	21	3.5	19	2.8	....	.....

* These checks were cultures in air-dry soil moistened and planted, with no other treatment. Average weight of the 6=3.5 grams.

tural soils, others may lie even beyond these limits. Only a comprehensive survey will give the complete range of this variance in toxicity. In addition, loss of toxicity varies with time and cropping, and largely determines the permanence of a given application in arid regions. Here again the sandy soils seem favored. Possibly with longer testing these differences will tend to diminish.

Besides soil differences, numerous weed species of varying characteristics are usually found in any given area. Plant species vary in susceptibility to toxic substances; but—more important in soil-sterilization practice—they vary in the character and depth of their root systems.

As indicated by the soil-tube tests on the fixing and leaching of arsenic in soils, this chemical will be held in the top layers of soil in fairly high concentrations and will remain there even after considerable rainfall. This is highly desirable in the control of annual weeds; but for deep-rooted perennials a greater penetration is needed. Here, again, the results of these studies have been confirmed in the field. In the Fresno

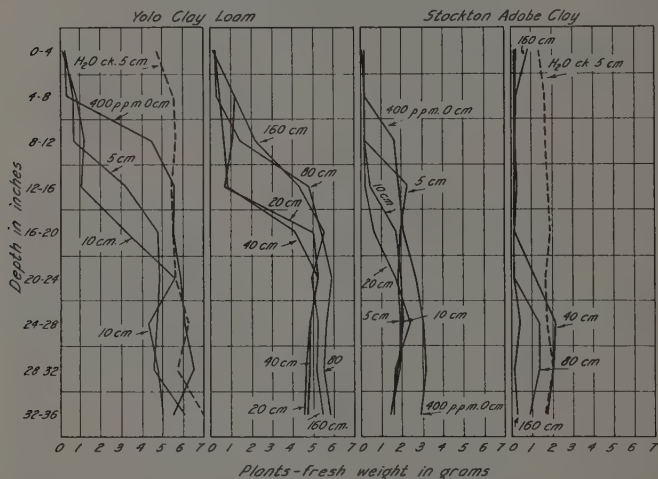


Fig. 9.—The effect of leaching upon the location of sodium arsenite in soil columns as shown by crop yield.

sandy loam, Bermuda grass may be controlled with a sodium arsenite application equivalent to 4 pounds of As_2O_3 per square rod. In the Yolo clay loam a similar application controlled annual weeds but not Bermuda grass.

Tests of these sterile soils indicate that the 4-pound application in the Fresno soil penetrated to a depth of 12 inches after a total rainfall of about 5 inches. In the Yolo soil, under similar conditions, the penetration was scarcely more than 2 inches. Though the method of application in the field differs considerably from that used in the soil-tube tests, the low fixing capacity and ready leaching in the Fresno sand, so apparent in these tests, allow considerable penetration in the field and work to an advantage where Bermuda grass is to be controlled.

One further difference between the soil-tube tests and field conditions should be noted. In the leaching tests the flow of water is slow but continuous. In the field the movement of water from rains is not only variable in rate but intermittent. The net effect in regions of fairly low

rainfall is to give less movement of the toxicant than would be expected on the basis of experiments. Tests conducted in March, 1934, on the location of the arsenic in the soil of plots on Fresno sandy loam that received 4 pounds in January, 1932, show it still to be in the highest concentration in the top 2 inches of soil. Though these plots have received over 40 centimeters of rainfall since the application, they have prob-

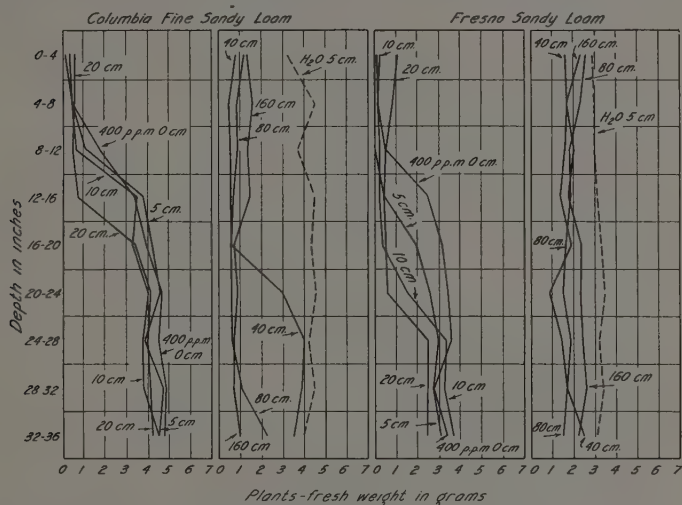


Fig. 10.—The effect of leaching upon the location of sodium arsenite in soil columns as shown by crop yield.

ably never been wet to a greater depth than 4 feet at any one time. In the tube tests the continuous application of 20 surface centimeters of water will wet a column of this soil 40 inches in height; and this continuous flow is the most effective factor in moving the arsenic.

Where light soils occur in regions of heavy rainfall, leaching of the toxicant from the soil would shorten the duration of a given treatment. Possibly this difficulty could be remedied by using arsenic in a less soluble form. The dry arsenic trioxide, though ineffective the first season after application, is apparently equal to an equivalent amount of sodium arsenite during succeeding seasons. This type of treatment may solve the problem where heavy rainfall causes excessive leaching. The question of deep penetration in heavy soils can probably be best answered by using sodium chlorate, a toxicant less firmly fixed and more readily leached than arsenic.

Evidently, therefore, though the results of the experiments with arsenic in soils that have been described are not directly applicable to soil-

sterilization practice in the field, they afford much useful information and answer many perplexing questions that could be solved by plot tests only after long and tedious work.

STUDIES WITH SODIUM CHLORATE

Experiments by Åslander^(1,2) and Muenscher⁽¹¹⁾ in New York, by Loomis and his coworkers^(9,10) in Iowa, and by the writer⁽⁶⁾ in Califor-

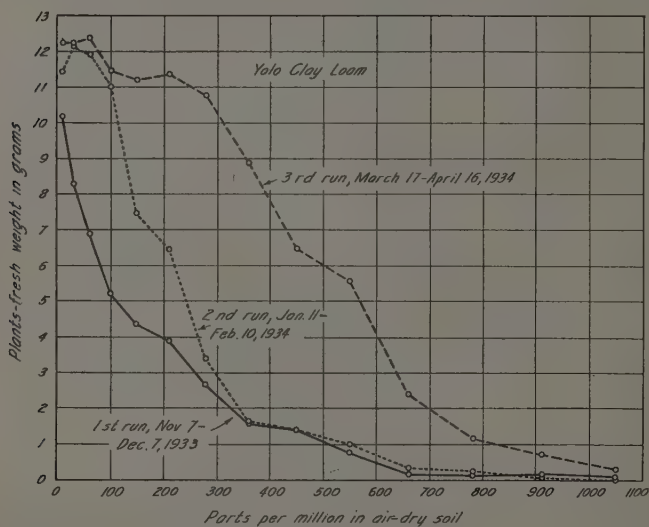


Fig. 11.—The relation of crop yield to the concentration of sodium chlorate in Yolo clay loam.

nia have demonstrated that sodium chlorate is toxic to plants when applied through the soil alone. Regardless of its action through the plant after absorption by foliar parts, it is an effective herbicide when used in the soil; and in arid regions, its toxic effects upon the roots of plants are important in any treatment of deep-rooted perennials. In California the most successful treatments are made just before or during the rainy season so that the chemical is soon carried into the soil, where it kills the roots and rhizomes of the plants and suffers little loss from decomposition.

Considering the importance of this method, as contrasted with the summer spraying so common in the East, a study of the behavior of chlorates in western soils seems desirable. With this in mind, experiments have been conducted to find the relative toxicity of sodium chlo-

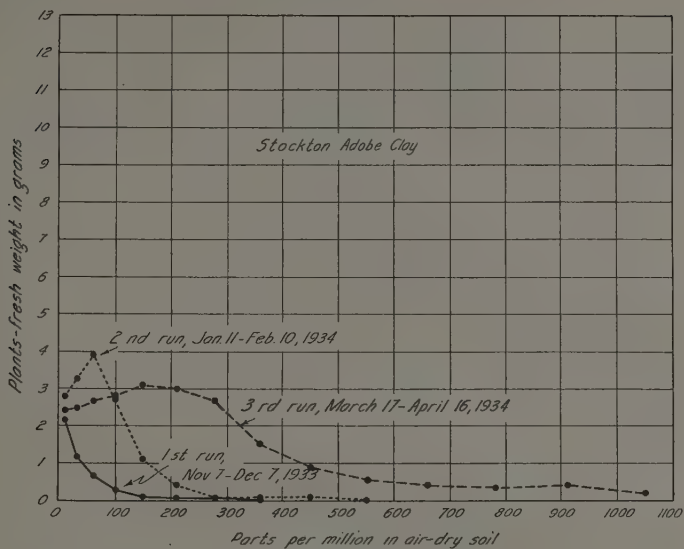


Fig. 12.—The relation of crop yield to the concentration of sodium chlorate in Stockton adobe clay.

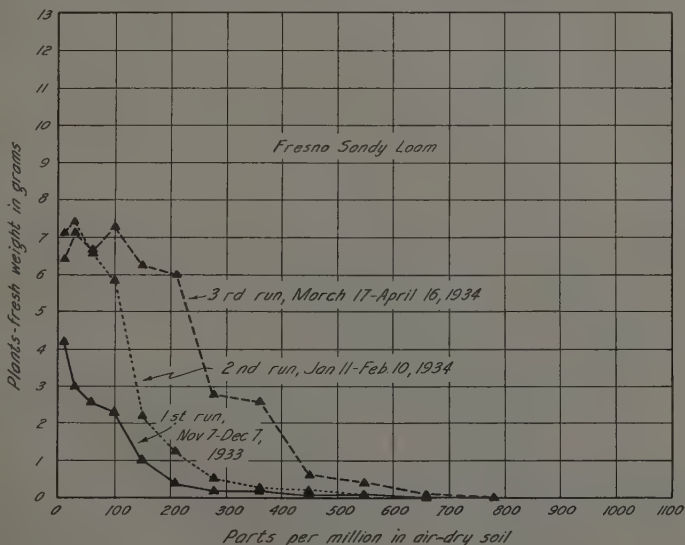


Fig. 13.—The relation of crop yield to the concentration of sodium chlorate in Fresno sandy loam.

rate in four California soils, the fixing power of these soils for chlorate, and the effects of leaching. The method and soils are essentially the same as those used in the studies with sodium arsenite.

The Toxicity Tests.—During the current season a series having 24 concentrations and 4 checks has been used in studying the toxicity of sodium chlorate. All concentrations and checks were replicated five

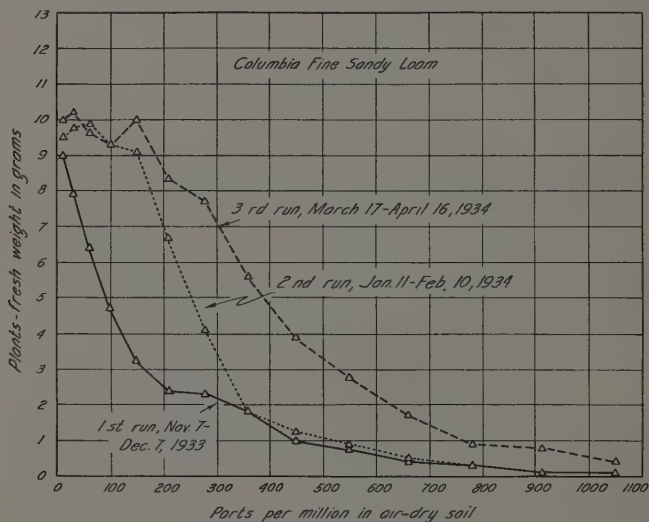


Fig. 14.—The relation of crop yield to the concentration of sodium chlorate in Columbia fine sandy loam.

times. The soils used were Yolo clay loam, Stockton adobe clay, Fresno sandy loam, and Columbia fine sandy loam. The data from the first three runs appear in table 9 and figures 11, 12, 13, and 14. Since all the differences shown in these runs appear within the first 14 concentrations, only these are included in the present report.

In general the data from these tests do not differ greatly from those on arsenic. The same wide differences in crop-producing power of the four soils are in evidence, and the correlation of low crops with high toxicity is somewhat more striking. There seems to be a higher degree of toxicity in the Stockton soil with chlorate than with arsenic, and inversely a lower toxicity in the Fresno soil.

Considering the three runs with chlorate, the third shows the greatest loss of toxicity (table 9), probably because of increasing tempera-

TABLE 9
TOXICITY OF SODIUM CHLORATE IN FOUR CALIFORNIA SOILS,
AS SHOWN BY GROWTH OF INDICATOR PLANTS

Sodium chlorate expressed as p.p.m. NaClO ₃ in the air-dry soil	Yolo clay loam		Stockton adobe clay		Fresno sandy loam		Columbia fine sandy loam	
	Height	Weight	Height	Weight	Height	Weight	Height	Weight

First run harvested December 7, 1933

	cm	gm	cm	gm	cm	gm	cm	gm
10.....	32	10.2	17	2.2	28	4.2	31	9.0
30.....	32	8.3	14	1.2	27	3.0	31	7.9
60.....	31	6.9	11	0.7	24	2.6	29	6.4
100.....	29	5.2	6	0.3	23	2.3	28	4.7
150.....	28	4.4	4	0.1	15	1.0	26	3.2
210.....	27	3.9	3	0.1	6	0.4	22	2.4
280.....	23	2.7	3	0.1	4	0.2	21	2.3
360.....	18	1.6	0	0.0	4	0.2	19	1.8
450.....	17	1.4	0	0.0	3	0.1	13	1.0
550.....	12	0.8	0	0.0	2	0.1	9	0.7
660.....	4	0.2	0	0.0	0	0.0	6	0.4
780.....	4	0.2	0	0.0	0	0.0	5	0.3
940.....	4	0.2	0	0.0	0	0.0	2	0.1
1,050.....	2	0.1	0	0.0	0	0.0	2	0.1
Check.....	31	11.1	17	2.3	29	6.0	30	9.2

Second run harvested February 10, 1934

	cm	gm	cm	gm	cm	gm	cm	gm
10.....	35	8.2	20	2.3	26	4.5	30	7.5
30.....	35	8.7	21	2.7	29	4.7	30	7.8
60.....	34	8.5	24	3.2	28	4.2	31	7.9
100.....	33	7.8	21	2.2	16	3.7	30	7.4
150.....	30	5.3	14	0.9	17	1.4	29	7.2
210.....	28	4.6	10	0.3	18	0.8	28	5.3
280.....	24	2.4	7	0.1	9	0.3	24	3.3
360.....	16	1.2	6	0.1	7	0.2	19	1.4
450.....	16	1.0	4	0.1	6	0.1	16	1.0
550.....	14	0.7	0	0.0	0	0.0	14	0.7
660.....	11	0.3	0	0.0	0	0.0	12	0.4
780.....	7	0.2	0	0.0	0	0.0	9	0.2
940.....	5	0.1	0	0.0	0	0.0	7	0.1
1,050.....	0	0.0	0	0.0	0	0.0	0	0.0
Check.....	33	7.9	18	1.9	24	3.8	30	7.3

Third run harvested April 16, 1934

	cm	gm	cm	gm	cm	gm	cm	gm
10.....	33	8.3	24	3.5	33	5.4	34	7.6
30.....	33	8.3	25	3.6	32	6.0	34	7.8
60.....	34	8.4	26	4.0	32	5.7	32	7.3
100.....	34	7.8	26	4.2	32	6.2	34	7.1
150.....	34	7.6	29	4.6	32	5.3	35	7.6
210.....	34	7.7	28	4.4	31	5.1	34	6.3
280.....	34	7.3	26	4.0	24	2.4	33	5.9
360.....	31	6.0	19	2.2	22	2.2	29	4.3
450.....	30	4.4	19	1.9	10	0.5	24	3.0
550.....	27	3.8	9	0.9	8	0.3	20	2.1
660.....	16	1.6	9	0.6	5	0.1	16	1.3
780.....	13	0.8	8	0.4	0	0.0	11	0.7
940.....	9	0.5	10	0.6	0	0.0	9	0.6
1,050.....	7	0.2	7	0.3	0	0.0	6	0.3
Check.....	30	7.5	23	3.4	30	5.1	32	7.0

ture with the advance of the season. As the Iowa workers⁽¹⁰⁾ have shown, chlorate decomposition is greater as temperatures are raised.

The Soil-Tube Tests.—The fixing power of the four soils is much less for chlorate than for arsenic. Since preliminary tests had indicated this

TABLE 10

EFFECT OF RATE OF WETTING UPON CHLORATE FIXATION BY YOLO CLAY LOAM AND FRESNO SANDY LOAM, AS SHOWN BY GROWTH OF INDICATOR PLANTS

Soil type	Depth	H ₂ O check 12 d.p.m.*		NaClO ₃ —200 p.p.m.									
				20 d.p.m.*		15 d.p.m.*		12 d.p.m.*		10 d.p.m.*		6 d.p.m.*	
		Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
	<i>inches</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>
Yolo clay loam; harvested Jan. 20, 1934	0.0-3.6	26	4.5	14	1.0	18	1.5	14	1.1	14	1.0	17	1.0
	3.6-7.2	24	4.1	16	1.0	9	0.6	16	1.2	16	0.9	11	0.7
	7.2-10.8	25	4.7	16	2.0	12	0.9	13	1.0	12	0.9	10	0.4
	10.8-14.4	27	5.5	12	1.0	7	0.3	11	0.7	15	0.7	15	0.9
	14.4-18.0	25	5.3	9	0.5	8	0.3	13	1.1	22	1.5	19	2.2
	18.0-21.6	25	5.7	10	0.9	12	0.6	17	2.0	22	3.3	28	6.6
	21.6-25.2	31	7.7	11	1.5	9	0.6	29	7.1	32	7.3	32	6.7
	25.2-28.8	32	7.6	29	6.9	30	6.9	32	8.0	32	7.5	36	7.3
	28.8-32.4	30	6.1	29	6.5	28	4.8	28	5.8	31	5.4	28	5.6
	32.4-36.0	30	5.9	28	6.1	29	5.2	28	5.4	29	5.5	28	5.6
Fresno sandy loam; harvested Jan. 20, 1934	0.0-3.6	19	2.7	6	0.1	5	0.1	6	0.2	8	0.2	6	0.3
	3.6-7.2	19	2.8	7	0.4	10	0.4	8	0.4	12	0.6	12	0.7
	7.2-10.8	21	3.2	10	0.6	13	0.7	10	0.5	6	0.3	6	0.3
	10.8-14.4	21	3.3	11	0.5	9	0.5	6	0.2	8	0.4	11	0.6
	14.4-18.0	23	3.9	10	0.7	13	0.9	9	0.5	9	0.4	8	0.4
	18.0-21.6	21	3.1	11	0.7	13	0.6	7	0.3	9	0.4	11	0.7
	21.6-25.2	22	3.6	11	0.6	13	0.7	9	0.5	14	1.1	15	0.9
	25.2-28.8	24	3.8	9	0.6	12	0.7	13	0.7	11	0.6	15	0.9
	28.8-32.4	26	4.6	14	1.0	15	0.8	10	0.8	16	1.5	17	1.0
	32.4-36.0	30	7.1	25	4.3	26	4.8	25	4.5	29	6.0	27	4.7

* In this table, "d.p.m." means drops per minute.

fact and since with low fixing power the rate of wetting of the soil columns might be a factor, an experiment was designed to clarify this point. The resultant data are given in table 10 and in figure 15. In Yolo clay loam, evidently, rate of wetting is important. More chlorate is taken from the solution at the lower rate of moistening, and the depth of penetration decreases. In the Fresno soil there were no differences.

In the practical problem of conducting these experiments, there are certain limits upon the method. The heavier soils cannot be moistened evenly at a rate much above 12 drops per minute from the tips used in these experiments. On the other hand, lowering the rate prolongs the process until it becomes tedious. This rate of 12 drops per minute was used in the following tests (tables 11 to 15) as in the arsenic studies. In considering the data being presented, one must remember that, had the

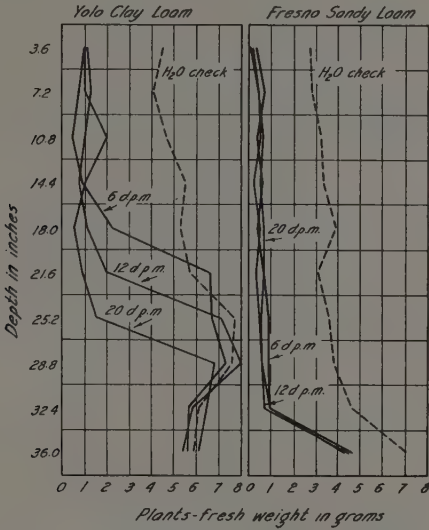


Fig. 15.—The effect of rate of wetting upon the location of sodium chlorate in soil columns as shown by crop yield. In this figure, "d.p.m." means drops per minute from standard tips.

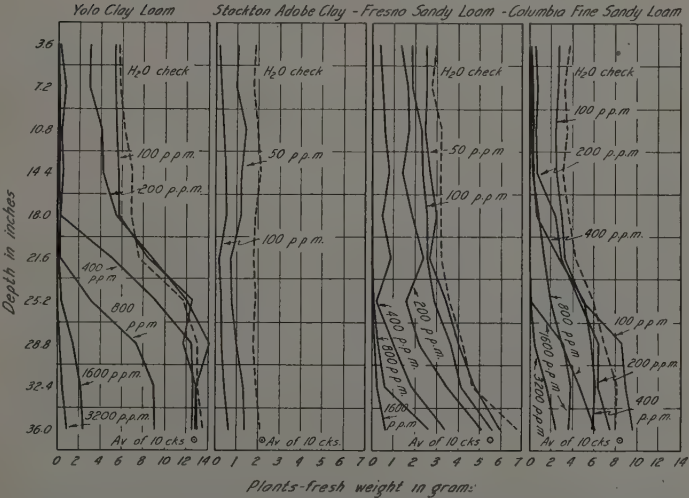


Fig. 16.—The relation of crop yield to penetration of sodium chlorate into columns of four California soils, showing their fixing power. Crops on the Yolo and Columbia soils were heavy and the scale had to be altered accordingly.

rate been slower, the fixing would have been somewhat greater in the Yolo and Columbia soils. Where the fixing is stronger, as with arsenic, the rate of moistening is less important.

Data on the fixing of chlorate in the four soils are presented in tables 11, 12, 13, and 14, and in figure 16. The method was changed slightly in

TABLE 11
THE FIXING POWER OF YOLO CLAY LOAM FOR SODIUM CHLORATE,
AS SHOWN BY GROWTH OF INDICATOR PLANTS*
(Harvested February 25, 1934)

Depth	H ₂ O check		NaClO ₃ 100 p.p.m.		NaClO ₃ 200 p.p.m.		NaClO ₃ 400 p.p.m.		NaClO ₃ 800 p.p.m.	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
<i>inches</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>
0.0-3.6	24	5.6	25	5.3	24	2.9	8	0.2	0	0.0
3.6-7.2	23	5.8	25	5.3	26	2.8	18	0.6	5	0.1
7.2-10.8	24	6.3	24	5.4	26	3.1	8	0.2	5	0.1
10.8-14.4	25	6.9	25	5.6	27	3.2	13	0.4	5	0.1
14.4-18.0	27	6.8	26	5.8	28	5.6	8	0.2	10	0.2
18.0-21.6	28	7.7	27	8.5	29	8.8	28	5.1	8	0.2
21.6-25.2	30	11.8	27	12.6	29	12.1	32	9.2	24	3.1
25.2-28.8	30	13.0	27	11.8	30	14.2	32	12.4	32	7.4
28.8-32.4	30	13.0	29	12.9	31	13.0	32	12.6	36	8.7
32.4-36.0	32	13.5	30	13.0	31	12.9	31	12.4	36	9.0

Depth	NaClO ₃ 1,600 p.p.m.		NaClO ₃ 3,200 p.p.m.		NaClO ₃ † 100 p.p.m.		NaClO ₃ † 400 p.p.m.		NaClO ₃ † 1,600 p.p.m.	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
<i>inches</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>
0.0-3.6	0	0.0	0	0.0	25	3.5	0	0.0	0	0.0
3.6-7.2	0	0.0	0	0.0	26	3.8	6	0.1	0	0.0
7.2-10.8	0	0.0	0	0.0	26	4.0	7	0.1	0	0.0
10.8-14.4	0	0.0	0	0.0	27	4.0	6	0.1	0	0.0
14.4-18.0	0	0.0	0	0.0	25	3.6	7	0.1	0	0.0
18.0-21.6	5	0.1	0	0.0	24	4.6	7	0.1	0	0.0
21.6-25.2	8	0.2	0	0.0	27	4.4	7	0.2	0	0.0
25.2-28.8	16	1.6	6	0.2	27	4.1	10	0.4	0	0.0
28.8-32.4	29	2.2	7	0.3	27	4.4	15	0.9	6	0.2
32.4-36.0	30	2.3	14	0.8	28	4.6	17	1.0	6	0.2

* Average weight of plants in 10 untreated checks=12.7 grams.

† The soil in the last three tubes was moistened before the sodium chlorate was applied. All other applications were to dry soil.

running these and subsequent soil-tube tests. In all previous tests the soil was measured into the cans by weight in fractionating the column. In some tubes certain fractions proved somewhat more moist than others, even after 24 to 48 hours had been allowed for the moisture to reach equilibrium. These moist fractions would contain less soil when placed in the cans and with the method of watering used would remain more moist throughout the experiment. Trials showed that fractiona-

tion into columns of equal height not only was quicker but resulted in a more uniform moisture condition in the various fractions. This method was adopted, the 36-inch column being divided into ten equal fractions,

TABLE 12
THE FIXING POWER OF STOCKTON ADOBE CLAY FOR SODIUM CHLORATE,
AS SHOWN BY GROWTH OF INDICATOR PLANTS*
(Harvested March 16, 1934)

Depth	H ₂ O check		NaClO ₃ 50 p.p.m.		NaClO ₃ 100 p.p.m.		NaClO ₃ 200 p.p.m.		NaClO ₃ 400 p.p.m.	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
<i>inches</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>
0.0- 3.6	16	1.9	11	1.1	8	0.2	0	0.0	0	0.0
3.6- 7.2	16	1.8	12	1.0	8	0.3	6	0.1	0	0.0
7.2-10.8	17	2.0	15	1.4	8	0.4	0	0.0	0	0.0
10.8-14.4	17	2.1	12	1.2	9	0.5	0	0.0	0	0.0
14.4-18.0	18	1.9	13	1.2	9	0.5	0	0.0	0	0.0
18.0-21.6	16	1.8	11	0.8	6	0.2	0	0.0	0	0.0
21.6-25.2	16	1.9	11	0.8	8	0.3	0	0.0	0	0.0
25.2-28.8	17	1.8	12	1.0	8	0.3	0	0.0	0	0.0
28.8-32.4	17	1.9	13	1.3	8	0.4	0	0.0	0	0.0
32.4-36.0	19	2.1	14	1.3	10	0.7	0	0.0	0	0.0

Depth	NaClO ₃ 800 p.p.m.		NaClO ₃ 1,600 p.p.m.		NaClO ₃ † 100 p.p.m.		NaClO ₃ † 400 p.p.m.		NaClO ₃ † 1,600 p.p.m.	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
<i>inches</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>
0.0- 3.6	0	0.0	0	0.0	10	0.7	0	0.0	0	0.0
3.6- 7.2	0	0.0	0	0.0	8	0.4	0	0.0	0	0.0
7.2-10.8	0	0.0	0	0.0	7	0.2	0	0.0	0	0.0
10.8-14.4	0	0.0	0	0.0	7	0.4	0	0.0	0	0.0
14.4-18.0	0	0.0	0	0.0	5	0.2	0	0.0	0	0.0
18.0-21.6	0	0.0	0	0.0	9	0.4	0	0.0	0	0.0
21.6-25.2	0	0.0	0	0.0	7	0.3	0	0.0	0	0.0
25.2-28.8	0	0.0	0	0.0	10	0.6	0	0.0	0	0.0
28.8-32.4	0	0.0	0	0.0	8	0.6	0	0.0	0	0.0
32.4-36.0	0	0.0	0	0.0	9	0.5	0	0.0	0	0.0

* Average weight of 10 untreated checks=2.2 grams.

† The soil in the last three tubes was moistened before the sodium chlorate was applied. All other applications were to dry soil.

each containing, theoretically, the weight of soil used in the other experiments.

In the tests on fixing power, ten tubes were used with each soil. The first was simply moistened with distilled water to show the effect upon readily soluble nutrients. Six dry columns of each soil were moistened with chlorate solutions of various concentrations, as indicated in tables 11 to 14. Three columns of each were moistened with distilled water, and then an equal volume of chlorate solution was applied in the same way, the object being to displace the original moisture with its dissolved nutrients and bring out the effect of chlorate solution alone.

As results with the dry tubes (fig. 16) show, chlorate is much less firmly fixed in these soils than is arsenic (fig. 8). In the Yolo and Columbia soils chlorate is held mostly within the upper halves of the col-

TABLE 13

THE FIXING POWER OF FRESNO SANDY LOAM FOR SODIUM CHLORATE,
AS SHOWN BY GROWTH OF INDICATOR PLANTS*
(Harvested March 2, 1934)

Depth	H ₂ O check		NaClO ₃ 50 p.p.m.		NaClO ₃ 100 p.p.m.		NaClO ₃ 200 p.p.m.		NaClO ₃ 400 p.p.m.	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
<i>inches</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>
0.0- 3.6	25	3.0	21	2.5	21	1.9	19	1.3	7	0.3
3.6- 7.2	21	2.8	20	2.5	19	1.9	22	1.7	11	0.5
7.2-10.8	22	3.2	21	2.4	23	2.3	21	1.7	10	0.6
10.8-14.4	20	3.2	24	2.7	23	2.3	20	1.4	12	0.8
14.4-18.0	21	3.2	24	3.0	23	2.5	21	1.9	9	0.4
18.0-21.6	23	3.2	21	2.7	23	2.5	22	2.4	13	0.9
21.6-25.2	25	3.6	23	3.4	24	2.9	21	1.6	7	0.2
25.2-28.8	23	4.2	26	4.0	26	3.6	22	2.2	11	1.0
28.8-32.4	26	4.7	27	4.8	27	4.1	26	3.5	22	1.9
32.4-36.0	28	6.8	30	6.0	28	5.6	29	5.1	27	3.4

Depth	NaClO ₃ 800 p.p.m.		NaClO ₃ 1,600 p.p.m.		NaClO ₃ † 50 p.p.m.		NaClO ₃ † 200 p.p.m.		NaClO ₃ † 800 p.p.m.	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
<i>inches</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>
0.0- 3.6	0	0.0	0	0.0	19	2.0	12	0.7	0	0.0
3.6- 7.2	0	0.0	0	0.0	17	2.0	21	1.3	0	0.0
7.2-10.8	0	0.0	0	0.0	18	2.1	14	0.9	5	0.1
10.8-14.4	0	0.0	0	0.0	19	2.0	16	1.0	5	0.1
14.4-18.0	0	0.0	0	0.0	20	2.1	20	1.2	5	0.1
18.0-21.6	0	0.0	0	0.0	21	2.4	10	0.9	5	0.1
21.6-25.2	4	0.1	0	0.0	21	2.4	20	1.4	0	0.0
25.2-28.8	5	0.2	5	0.1	23	2.7	18	1.4	5	0.1
28.8-32.4	10	0.6	5	0.2	22	2.5	17	1.0	6	0.1
32.4-36.0	29	2.7	12	0.7	24	2.9	19	1.5	6	0.1

* Average weight of 10 untreated checks=5.5 grams.

† The soil in the last three tubes was moistened before the sodium chlorate was applied. All other applications were to dry soil.

umns; in the Fresno soil it penetrated almost to the lowest fraction; and in the Stockton soil it was apparently free to move with the moisture, there being no evidence of fixation whatever. The differences in initial toxicity are reflected in these curves and agree with those previously observed.

In the moistened tubes the nutrients were removed as expected; and one other feature appears, at least in the Yolo soil. The toxicity seems consistently higher in the moistened columns of this soil, and slight differences of the same nature occur in the Fresno soil. Since heavy leach-

ing tends to reduce somewhat the crop-producing power of the soil, the toxicity is increased as might be expected.

Since the breaks in the curves in figure 16 are not sharp, values for the fixing power of these soils, calculated as for arsenic, are not exact.

TABLE 14
THE FIXING POWER OF COLUMBIA FINE SANDY LOAM FOR SODIUM CHLORATE,
AS SHOWN BY GROWTH OF INDICATOR PLANTS*
(Harvested April 3, 1934)

Depth	H ₂ O check		NaClO ₃ 100 p.p.m.		NaClO ₃ 200 p.p.m.		NaClO ₃ 400 p.p.m.		NaClO ₃ 800 p.p.m.	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
<i>inches</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>
0.0-3.6	26	3.9	26	2.7	10	0.5	7	0.1	8	0.1
3.6-7.2	23	3.3	26	2.6	14	0.7	8	0.1	5	0.1
7.2-10.8	24	3.5	22	2.4	14	0.6	8	0.1	5	0.1
10.8-14.4	26	3.0	24	2.5	13	0.7	14	0.2	18	0.2
14.4-18.0	26	3.7	25	3.0	27	2.4	14	0.6	13	0.8
18.0-21.6	26	4.2	29	3.3	28	3.0	28	2.9	20	1.3
21.6-25.2	31	6.0	32	4.8	30	4.6	31	5.0	18	2.0
25.2-28.8	31	6.9	32	8.5	31	6.4	34	5.8	25	3.0
28.8-32.4	33	8.1	36	9.0	32	6.3	31	6.1	31	4.6
32.4-36.0	32	8.0	35	9.7	32	7.5	31	5.9	31	6.1

Depth	NaClO ₃ 1,600 p.p.m.		NaClO ₃ 3,200 p.p.m.		NaClO ₃ † 100 p.p.m.		NaClO ₃ † 400 p.p.m.		NaClO ₃ † 1,600 p.p.m.	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
<i>inches</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>
0.0-3.6	0	0.0	0	0.0	23	2.6	6	0.1	0	0.0
3.6-7.2	0	0.0	0	0.0	23	2.7	7	0.3	0	0.0
7.2-10.8	0	0.0	0	0.0	24	2.6	5	0.1	0	0.0
10.8-14.4	0	0.0	0	0.0	24	3.2	5	0.1	0	0.0
14.4-18.0	0	0.0	0	0.0	25	3.3	6	0.1	0	0.0
18.0-21.6	0	0.0	0	0.0	26	3.1	6	0.1	0	0.0
21.6-25.2	6	0.1	6	0.1	25	3.4	21	1.7	6	0.1
25.2-28.8	26	3.2	9	0.4	26	2.8	22	2.1	0	0.0
28.8-32.4	29	3.9	25	1.8	26	3.1	23	2.9	0	0.0
32.4-36.0	29	3.7	21	2.4	26	3.3	24	3.0	6	0.1

* Average weight of 10 untreated checks=8.4 grams.

† The soil in the last three tubes was moistened before the sodium chlorate was applied. All other applications were to dry soil.

Obviously the column cannot be divided into two parts, one containing chlorate and the other free from it. The concentration of chlorate decreases gradually downward, especially in the Columbia and Fresno soils; and an average value for the concentration in the upper portion of the tube would not be accurate. Estimates have been made, however, which, though only approximate, are interesting to contrast with those made for the arsenic. For instance, in the tubes moistened with solutions containing 800 p.p.m. of sodium chlorate, the values for the concentration fixed, based on air-dry soil, are as follows: Yolo clay loam, 110

p.p.m.; Stockton adobe clay, 0 p.p.m.; Fresno sandy loam, 16 p.p.m.; Columbia fine sandy loam, 80 p.p.m. Corresponding values for sodium arsenite were Yolo clay loam, 480 p.p.m.; Stockton adobe clay, 280 p.p.m.; Fresno sandy loam, 131 p.p.m.; Columbia fine sandy loam, 335 p.p.m. The greatest difference is shown by the Stockton soil, which,

TABLE 15
RESULTS OF LEACHING TESTS WITH SODIUM CHLORATE* IN CALIFORNIA SOILS,
AS SHOWN BY GROWTH OF INDICATOR PLANTS

Soil Type, NaClO ₃ concentration, and harvesting date (1934)	Depth	5 cm H ₂ O		10 cm H ₂ O		20 cm H ₂ O		40 cm H ₂ O	
		Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
Yolo clay loam; 150 cc NaClO ₃ solu- tion* previously applied; harvested May 18	<i>inches</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>
	0.0-3.6	10	0.9	20	2.9	22	4.2	25	5.7
	3.6-7.2	10	1.1	17	2.2	22	3.8	28	6.1
	7.2-10.8	12	1.5	12	1.5	20	2.5	27	6.2
	10.8-14.4	14	1.9	12	1.1	20	3.1	25	5.6
	14.4-18.0	15	2.2	12	1.4	20	2.7	28	6.7
	18.0-21.6	20	4.3	11	1.1	20	3.0	25	6.0
	21.6-25.2	26	7.0	15	2.4	19	2.1	30	6.4
	25.2-28.8	28	7.4	17	3.7	19	2.4	28	6.0
	28.8-32.4	25	7.2	24	5.6	20	3.1	26	6.1
Stockton adobe clay; 140 cc NaClO ₃ solu- tion* previously applied; harvested April 30	32.4-36.0	26	7.3	25	7.0	23	5.2	27	6.5
	0.0-3.6	4	0.1	27	2.5	28	2.7	23	2.3
	3.6-7.2	4	0.1	17	1.1	25	2.8	25	2.2
	7.2-10.8	4	0.1	6	0.3	20	1.9	22	2.0
	10.8-14.4	6	0.2	4	0.1	25	2.4	23	2.4
	14.4-18.0	21	1.8	4	0.1	20	1.4	25	2.6
	18.0-21.6	24	2.6	5	0.2	16	1.0	25	2.3
	21.6-25.2	22	2.1	6	0.4	6	0.2	23	2.5
	25.2-28.8	22	1.9	15	1.1	4	0.1	23	2.4
	28.8-32.4	25	2.2	21	1.7	4	0.1	24	2.3
Fresno sandy loam; 90 cc NaClO ₃ solu- tion* previously applied; harvested April 19	32.4-36.0	22	2.3	22	2.0	5	0.1	21	1.8
	0.0-3.6	21	3.4	21	4.0	20	3.7	19	3.5
	3.6-7.2	22	3.3	21	4.1	21	3.7	20	3.7
	7.2-10.8	22	2.2	20	3.7	21	4.1	19	3.8
	10.8-14.4	15	1.2	23	2.8	20	3.9	21	4.3
	14.4-18.0	10	0.9	22	3.7	20	4.2	20	4.6
	18.0-21.6	10	0.6	20	2.1	20	4.2	21	4.2
	21.6-25.2	15	1.3	8	0.3	20	3.9	21	4.4
	25.2-28.8	24	2.7	8	0.3	21	3.7	21	4.1
	28.8-32.4	25	3.6	8	0.4	22	3.1	20	4.1
Columbia fine sandy loam; 100 cc NaClO ₃ solution* previously applied; harvested April 21	32.4-36.0	25	3.3	20	1.9	17	1.8	20	3.9
	0.0-3.6	9	0.6	18	2.0	21	4.0	21	4.5
	3.6-7.2	5	0.1	3	0.1	19	3.2	22	5.3
	7.2-10.8	3	0.1	3	0.1	3	0.5	22	4.8
	10.8-14.4	3	0.1	8	0.7	3	0.1	21	4.5
	14.4-18.0	18	1.9	6	0.2	4	0.2	21	4.5
	18.0-21.6	24	4.7	7	0.5	14	1.3	21	3.6
	21.6-25.2	23	5.5	14	1.1	22	2.7	21	3.9
	25.2-28.8	25	5.5	21	2.3	23	3.1	21	4.1
	28.8-32.4	27	6.7	22	2.8	20	3.1	24	3.9
	32.4-36.0	30	6.9	22	3.4	21	4.1	21	4.2

* Shortly before leaching, a 4,000-p.p.m. solution of sodium chlorate was applied to the soils, in amounts varying with the soil type, as indicated.

though highly colloidal, apparently has no power to hold sodium chlorate above the concentration applied.

Since the fixing power for chlorate is so low, the method previously used in the leaching tests had to be changed. The tubes of soil in these experiments were first moistened slowly with water. Next, the amount of sodium chlorate equivalent to 400 p.p.m. in the volume used for mois-

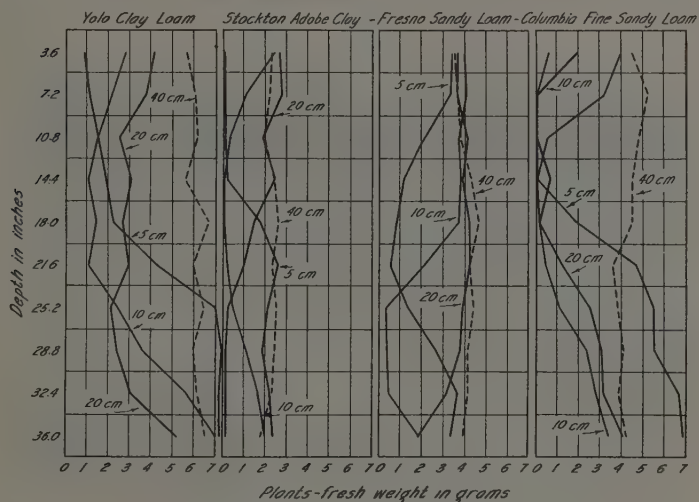


Fig. 17.—The effect of leaching upon the location of sodium chlorate in soil columns as shown by crop yield.

tening was applied, dissolved in one-tenth of this volume or in the volume necessary to moisten the top fraction. After a short time, leaching was started with distilled water. All water and solutions were applied at a rate of 12 drops per minute. The data from these tests appear in table 15; the graphs in figure 17.

These experiments serve to illustrate the relation between moving water in the soil and the location and distribution of chlorate. With low fixing power the chemical moves freely with soil moisture and is displaced readily, whereas with greater fixing power it tends to lag, and greater amounts of water are required to effect a given vertical movement. The differences observed in these tests are great enough to be significant in the field, and they serve to explain many of the anomalous results reported in field trials.

To be of practical value, this work must be repeated in the field in a large number of soils and under a variety of conditions. Though cer-

tain clues may be taken from plot tests,⁽⁶⁾ definite knowledge of the behavior of chlorates in soils must be obtained by soil-testing methods that are subject to considerable control.

One practical application of the testing method described has been made in studying the location and concentration of chlorate residues in the field. Application of chlorate to areas of morning-glory in a field at Davis in the fall of 1930 resulted in sterile spots that were still very much



Fig. 18.—Chlorate spots in a planting of fenugreek in a field at Davis. Sodium chlorate was applied in the fall of 1930 at a rate that probably reached 6 pounds per square rod in heavily infested areas. This picture was taken in April, 1933.

in evidence three years later (fig. 18). In May, 1933, the soil was sampled at various depths in these sterile areas and in adjacent fertile areas. Check series were established, using various concentrations of sodium chlorate in the fertile soils from different depths, and corresponding test cultures were made from the sterile areas. By checking the latter against the check series, the approximate concentration of chlorate at the different depths was found. Data from these tests appear in table 16.

The table shows that the top 8 inches of soil contained chlorate at a concentration of 400 p.p.m., or above. A careful comparison of the cultures indicates the following concentrations in the various fractions: 0–2 inches, 500 p.p.m.; 2–4 inches, 400 p.p.m.; 4–8 inches, 800 p.p.m.; 8–12 inches, 150 p.p.m.; 12–16 inches, 50 p.p.m.; 16–20 inches, 25 p.p.m.

After these determinations, the field containing these sterile areas was diked and irrigated, water being applied almost continuously until 36

inches had passed through the soil. As soon as the soil had dried sufficiently for sampling, 25 samples were taken from the area illustrated in figure 18. The A samples were taken at intervals of 1 rod along the dike, which appears as a barren strip a bit above center on the left side of the

TABLE 16

TOXICITY OF SODIUM CHLORATE IN YOLO FINE SANDY LOAM FROM FIELD THREE YEARS AFTER APPLICATION, AS COMPARED WITH THAT FROM SAMPLES HAVING KNOWN CONCENTRATIONS
(Toxicity shown by growth of indicator plants)

Source of sample	NaClO ₃ added, p.p.m. of air-dry soil	Depth from which sample was taken											
		0-2 inches		2-4 inches		4-8 inches*		8-12 inches*		12-16 inches*		16-20 inches*	
		Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
	p.p.m.	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm
Chlorate spot No. 1.....	2	0.1	3	0.1	0	0.0	3	0.1	11	0.6	16	1.5	
Chlorate spot No. 2.....	3	0.1	4	0.1	0	0.0	4	0.1	9	0.6	15	1.2	
Check series with known concentrations of NaClO ₃	25	17	1.3	16	1.2	16*	1.3*	.....*	.....*	16*	1.3***
	50	12	1.0	13	0.9	8	0.6	.....	.....	12	0.7	.....	.....
	100	8	0.5	6	0.4	5	0.3	.....	.....	5	0.3	.....	.....
	200	4	0.2	4	0.2	2	0.1	.....	.....	4	0.1	.....	.....
	400	4	0.2	3	0.1	2	0.1	.....	.....	1	0.1	.....	.....
	600	0	0.1	0	0.0	0	0.0	.....	.....	0	0.0	.....	.....
	800	0	0.0	0	0.0	0	0.0	.....	.....	0	0.0	.....	.....
	1,000	0	0.0	0	0.0	0	0.0	.....	.....	0	0.0	.....	.....
Checks with no NaClO ₃ added	0	17	2.2	17	2.2	16*	2.4*	.....*	.....*	16*	2.0***
	0	16	2.2	17	2.4	17	2.5	.....	.....	17	2.2	.....	.....

* In the check series, the 4-8 inch and 8-12 inch samples were combined, and likewise the 12-16 inch and 16-20 inch samples.

picture. The B samples were taken through the strip of normal vegetation to the right of the dike, the C and D samples from the barren area in the foreground, and the E samples from an adjoining check on the right that had never been treated with chlorate. The checks were samples of air-dry soil from bins in the head-house. Table 17 shows the growth of plants in these samples.

The only sample showing definite signs of chlorate effect was A4. Since these samples were all from the top 4 inches and since the top of the dike was not entirely wet by the irrigation water, this particular sample probably was not leached completely.

Samples to a depth of 42 inches were taken at a number of these locations; the results appear in table 18.

Here again the only significant differences appear in the soil of the A4 position. The higher concentration of chlorate at the lower levels indicates that lateral movement of water was sufficient to move the chlorate

down in the soil under the dike but to a lesser extent than in the flooded areas. Location E3 was outside the flooded area, and the greater crop in the top two samples gives a measure of the effects of the flooding on the treated areas. As these results show, leaching is a satisfactory method for removing chlorate from the soil. Different soil types react differently, however; and a testing method such as the one described should give a practical means for determining the effectiveness of a given treatment. Samples can be taken while the soil is fairly moist; and, if the chlorate has not been sufficiently displaced, leaching could be resumed with little loss of time or effort. The field mentioned above was planted

TABLE 17

GROWTH OF OATS IN SOILS FROM LEACHED CHLORATE SPOTS AND UNTREATED SOILS

Sample	Series A		Series B		Series C		Series D		Series E		Check	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm	cm	gm
1.....	20	3.7	18	3.2	17	2.9	18	2.8	18	3.1	17	2.7
2.....	17	2.4	19	3.5	18	3.3	19	3.5	19	3.7	18	2.9
3.....	17	3.0	17	3.3	18	3.1	18	3.2	18	3.1	18	2.9
4.....	14	1.7	20	3.9	19	3.0	19	3.2	20	3.6	20	2.9
5.....	18	3.3	20	3.2	19	2.9	19	2.7	22	3.9	19	2.5

to alfalfa in February, 1934; and the crop had shown no effect of chlorate by August, 1934, and appeared entirely normal.

Possibly a testing method similar to the one just described can be devised for studying the distribution of chlorate, applied under a certain degree of control, to various soils in the field. Such studies would form a connecting link between greenhouse work and plot tests and should give a much more accurate picture of the behavior of chlorate in soils and its effects upon plants than has been obtained from plot work alone.

Discussion of Sodium Chlorate Studies.—Though the spraying of growing weeds is commonly practiced and though certain chemical sprays are fairly effective against deep-rooted perennials, treatments designed to kill such weeds by foliar absorption and translocation of the poison through the plant are subject to a rigid set of requirements. When all these can be met, the acid arsenical method^(4, 5) seems the logical one to use, being low in initial cost and having no residual effects. Where these requirements cannot be met, sodium chlorate seems to promise the greatest general usefulness. Under these conditions, however, the principal action of chlorate is apparently through the soil by root absorption.

In order to make the most efficient use of chlorate by this method, its behavior in soils should be known. Its toxic limits, as determined by soil

type and species susceptibility, are important; and its general reaction to the quantity and movement of soil moisture must be understood.

The results reported in this paper show the large differences in toxicity encountered in soil types that may not be widely separated in the field. The soil-tube tests indicate the nature of the forces involved in the penetration of chlorate into soils and the requirements for its movement and removal. The companion paper in this issue⁽⁶⁾ indicated the type of plant responses that follow the use of chlorates. This information, coupled with an accurate knowledge of the root distribution of noxious weeds, should provide a more logical basis for experimental

TABLE 18
DISTRIBUTION OF CHLORATE IN THE SOIL OF LEACHED CHLORATE SPOTS,
AS SHOWN BY GROWTH OF INDICATOR PLANTS

Depth	Sample A-4		Sample B-3		Sample C-2		Sample C-4		Sample D-1		Sample D-5		Sample E-3	
	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.
<i>inches</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>	<i>cm</i>	<i>gm</i>
0-6	11	0.8	18	2.5	18	2.6	18	2.9	18	2.5	17	1.9	22	3.6
6-12	14	1.2	18	2.6	18	2.5	17	2.1	14	2.0	16	2.0	22	3.2
12-18	15	1.4	16	2.4	19	2.7	17	2.5	17	2.8	18	2.1	17	2.2
18-24	16	1.5	16	1.8	16	2.2	19	2.4	16	1.7	20	2.3	18	2.4
24-30	15	1.2	17	1.8	17	2.0	15	1.5	16	2.0	16	1.5	19	2.3
30-36	9	0.6	17	1.7	19	2.4	18	2.0	17	2.0	15	1.5	17	1.9
36-42	9	0.5	16	1.5	19	1.7	18	1.6	16	1.7	15	1.4	18	2.0

work on control methods than has been available in the past. Though the results of the experiments described in the present paper are fragmentary and apply only to the four soils used, with liberal interpretation in their application they should point the way to more critical work under field conditions. At least they indicate the possibility of developing an accurate and reliable weed control practice.

SUMMARY

Sodium Arsenite.—Variable results from field-plot tests on soil sterilization with sodium arsenite indicate the need for definite knowledge concerning the toxicity and fixing of this chemical in California soils.

A method has been developed for studying these problems by using a biological test for the toxicant in soils.

Compared with several soil sterilants on a cost basis, trivalent arsenic proved to be the most feasible chemical for soil sterilization.

Toxicity of arsenic was greatest in Fresno sandy loam and lowest in Yolo clay loam. Stockton adobe clay and Columbia fine sandy loam were intermediate.

Loss of toxicity with time and cropping was greatest in the Yolo soil and lowest in Fresno sandy loam. Here, again, the other two soils were intermediate.

Yolo clay loam has the strongest fixing power for arsenic, being able to hold over four times as much as Fresno sandy loam from solutions of equal concentration. The Stockton and Columbia soils held somewhat over twice as much.

The amount of arsenic held by all four soils was greater with increased concentration of the solutions applied.

The strong fixing of arsenic in the Yolo clay loam was shown again in the leaching tests. After movement of 160 surface centimeters of water through the soil, the top 4 inches was still sterile, and the chemical had not gone down below the 16-inch level.

Arsenic moved down through Stockton adobe clay more readily with leaching. With 160 surface centimeters of leaching, toxicity had decreased in the top 4 inches, but the remainder of the column was sterile.

Columbia fine sandy loam was intermediate between the Yolo and Stockton in the leaching tests.

Fresno sandy loam showed the lowest fixing power. Leaching with 160 surface centimeters of water practically removed the toxicant from the soil column.

Though the results of these experiments cannot be applied directly to soil sterilization in the field, the knowledge gained is very valuable in interpreting field-plot tests and has an integral part in developing an intelligent practice.

Sodium Chlorate.—Experiments indicate that the most successful use of sodium chlorate as a herbicide results from soil application and absorption by roots. For optimum results by this method the operator should understand the behavior of chlorate in soils.

Toxicity of sodium chlorate was highest in Stockton adobe clay and lowest in Yolo clay loam. It was only slightly higher in the Columbia fine sandy loam and intermediate in Fresno sandy loam.

The loss of toxicity with cropping was greater with the third crop than with the second. This is probably related to the increasing temperature as the season advanced.

The fixing power of the four soils was much less for chlorate than for sodium arsenite.

In the Yolo clay loam more chemical was fixed from a slowly moving solution. Rate of moistening had no effect in the Fresno sandy loam.

The Yolo and Columbia soils were able to hold the chemical within the top halves of the 36-inch columns from solutions up to 400 p.p.m. in concentration. In the Fresno soil it penetrated through nine-tenths of

the columns. The Stockton soil apparently has no fixing power for sodium chlorate.

Chlorate toxicity was higher in columns previously moistened with distilled water than in those moistened only with the chlorate solutions.

Leaching with distilled water moved the chlorate downward in the soil columns. Forty surface centimeters of water were sufficient to remove the chlorate from the Yolo and Columbia soils. Even less water was required to leach the other two soils free of chemical.

Sodium chlorate was present in the top 20 inches of the soil from sterile areas in a field sprayed three years previously to kill morning-glory.

Leaching with 36 surface inches of irrigation water successfully removed the chemical, and alfalfa was subsequently seeded. No toxic effect could be observed in the alfalfa during the first year.

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